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Study of the effect of climate parameters on the soil temperature,

Application “Air–Soil heat exchanger”

The jury members:

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بسم الله الرحمن الرحيم

Dedication:

" نُهدي مذكّرتنا لأمّتنا الإسلامية ووالدينا (حفظهم الله)
وإخوتنا وكل عائلتنا وأصدقائنا وكل طالب علم يعمل بجدٍّ. نرجو أن يُنقَّح
هذا العمل في قائمة المعرفة التي تفيد البشرية "

**"We dedicate our thesis to our Islamic nation,
our parents (Allah protect them), our brothers,
all our family and friends, and every hard-working
science student. We hope that this work will be revised
in the list of knowledge that benefits humanity."**

Acknowledgements:

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نودُّ أن نوجِّه خالص التقدير **لوالدينا** الأعزَّاء الذين قدَّموا لنا الدَّعم المعنوي والمادي، ونودُّ ان نعرِب عن إمتناننا **لعائلتنا** و**أصدقائنا** لمساعدتهم لنا. كما نشكر كل **فريق التكوين** الذين تكونَّا على أيديهم خلال مسارنا التعليمي، ونخص بالذكر منهم:

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فجزاهم الله عنَّا خيرا ورفع قدرهم في الدارين.

Figures list:

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Nomenclature:

Glossary:

T: Temperature, **°C**.

T_{Amp}: The amplitude of surface temperature, **°C**.

T_{mean} : Soil's average temperature, **°C**.

$T_{air_{amb}}$: The outside ambient temperature, **°C**.

T_{air}**:** The absolute temperature of the air adjacent to the ground surface, **°C**.

T_{soil}: The undisturbed soil temperature, **°C**.

T (z, t): Soil temperature at time t and depth z, **°C**.

T_{in}: The temperature at the inlet of the EAHE, **°C**.

T_{out}: The temperature at the outlet of the EAHE, **°C**.

t :Time, **h**.

t_0: The hour of the year with the maximum temperature value of the surface, **h**.

V: Velocity, **m/s**.

$\dot{m}$: Mass flow rate of fluid, **kg/s**.

Cp**:** Specific heat capacity, **J/kg·K**.

x: Cartesian coordinate

z: Depth, **m**.

L**:** Pipe length **m**.

U: The overall heat transfer coefficient between air and soil, **W/m·K**.

R_{tot} : The total thermal resistance of the system, **m²·K/W**.

R_{conv} : Thermal convective resistance between the airflow and the inner pipe surface, **m²·K /W**.

R_{cond}: Thermal conductive resistance of the pipe, **m²·K /W**.

R_{soil}: Thermal resistance between the outer pipe surface and the ground, **m²·K /W**.

h_{conv}: Convective heat transfer coefficient, **W/m²·K**.

al: The albedo surface associated with the ground surface type, **dimensionless**.

C_{cloud}**:** The fractional cloud cover coefficient, **dimensionless**.

ε_{lw}^{A}**:** The long-wave emissivity of the air at ground level, **dimensionless**.

ε_{lw}^{s}**:** The long-wave emissivity of the body, **dimensionless**.

G_{cond}**:** The total radiation heat flux absorbed or emitted at the soil surface, **W/m²**.

$SW^{absorbed}$**:** The adsorbed shortwave radiation flux, **W/m²**.

LW^{net}**:** The net long-wave radiation flux, **W/m²**.

$LW^{emitted}$**:** The radiation flux emitted from the ground surface, **W/m²**.

EV**:** The latent heat flux, **W/m²**.

H**:** The sensible heat flux, **W/m²**.

Greek Letters:

α: Thermal diffusivity, **m²/s**.

σ**:** Stefan– Boltzmann constant, **W/m²·K⁴**.

ε: Emissivity, **dimensionless**.

ρ: Density, **kg/m³**.

λ: Heat conductivity, **W/m·K**.

μ : Dynamic viscosity, **kg/m·s**.

ω : Annual angular frequency, **rad/h**.

Dimensionless groups:

Re: Reynold number.

Pr: Prandtl number.

Nu: Nusselt number.

Subscripts:

in, pipe	inside pipe
out, pipe	outside pipe
air	Air
wind	Wind
soil	Soil
conv	Convection
cond	Conduction
out	Outlet
in	Inlet
min	Minimum
max	Maximum

Abbreviations:

RES: Renewable energy sources.

EAHE: Earth-to-air heat exchangers.

FVM: Finite volume method.

Contents:

GENERAL INTRODUCTION

Buildings are responsible for approximately 40% of global energy consumption and for one-third of total energy greenhouse gas emissions. The biggest part of the energy consumed in the building sector is used for space heating and cooling, which cover almost one third of total energy demand. The use of conventional systems for building heating/cooling requirements present a significant energy and environmental impact, such as increase of carbon dioxide (CO2) emissions; global warming; aggravation of greenhouse and urban heat island effects; increase of peak electric load demands; degradation of indoor air quality, etc. During the last decades, the scientific and technical community has made a great effort to explore and investigate the most energy efficient solutions, based on renewable energy sources **(RES)**, for space heating/cooling which could simultaneously contribute to energy conservation and environmental protection **[1]**.

The ground temperature at shallow depths is predominantly a function of the upper surface processes – that is, climatic parameters such as solar radiation and ambient air temperature. The ground located in closest proximity to the surface is subject to the greatest changes due to climatic variations and atmospheric conditions **[2]**.

Earth-to-air heat exchangers **(EAHE**) use ground as a heat sink/source and consist of a single or multiple pipes buried in the ground, through which ambient or indoor air is circulated and heat is transferred from the air to the soil during the summer (cooling mode) or from the soil to the air during the winter (heating mode). The air at the outlet of the pipes is mixed with the indoor air of a building or an agricultural greenhouse. The thermal performance of EAHE is strongly influenced by many parameters, which could be classified in three main categories: (a) system design parameters, such as pipe material, pipe length, pipe radius, burial depth, and number of pipes; (b) different soil types described and expressed by the thermophysical properties of the soil profile, such as moisture content, thermal conductivity, specific heat capacity, and thermal diffusivity; (c) environmental parameters responsible for the temperature distribution of the ground surface, such as short and long-wave radiation, convective heat transfer, wind speed, vegetation and ground surface coverage, and evaporation/condensation speed.

(**Figure 1)** represents a single EAHE including the most important environmental and heat transfer processes influencing the thermal performance of the system; these may be summarized as follows: **(a)** environmental and thermophysical processes responsible for the temperature distribution at the surface and various depths of the ground, such as short and long wave radiation, convective heat flux, ground surface coverage, evaporation, and wind speed; and **(b)** heat transfer mechanisms in the soil and pipe, including conduction in the soil and convection inside the pipe **[1]**.

Fig.1. EAHE and main environmental and heat transfer mechanisms affecting system performance **[1]**.

Memoire layout will be as follows :

This memoire consist of General Introduction, 4 chapters and General Conclusion.

First Chapter (**I**) is "**Literature Review**". This chapter present the literature review related to the study. This chapter includes heat energy balance at the soil atmospheric interface, and the works done on the EAHE systems on the world and in Algeria.

Second Chapter (**II**) is "**Global Warming and EAHE systems**" This chapter includes the problem of global warming and EAHE systems, which lies in these systems being one way to reduce them. An overview of these systems, their types and parameters affecting thermal reduction, for eg the length of pipe and tube material and the depth of burial, as well as the type of soil used, was mentioned.

Third Chapter (**III**) is "**Theoretical Study**". This chapter explains the Theoretical study adopted in this study. This chapter covers Brief review on heat transfer modes, ground properties, The mathematical modeling of heat balance on the ground surface, EAHE, soil temperatue and ambient temperature.

Lastly is the Forth Chapter (**IV**), which is "**Numerical resolution, Results and discussion**", in this chapter we will talk about how to solve the problem and the tools used and then show and discuss the results.

References :

[1] Mihalakakou, G., Souliotis, M., Papadaki, M., Halkos, G., Paravantis, J., Makridis, S., & Papaefthimiou, S. (2021). Applications of earth-to-air heat exchangers: A holistic review. *Renewable and Sustainable Energy Reviews*, 111921.

[2] Sedighi, M., Hepburn, B. D., Thomas, H. R., & Vardon, P. J. (2016). Energy balance at the soil atmospheric interface. *Environmental Geotechnics*, *5*(3), 146-157.

CHAPTER

I

Literature review

I .1.Introduction:

In order to situate our work, we present in this chapter the previous works in relation to our theme of study. Bibliographic studies touch the most important points that are main in this memoire: Ground surface energy balance and soil temperature, and which are predicting outlet air temperature of (EAHE) system.

I .2. The Works done on energy balance at the soil atmospheric interface and (EAHE) systems according to chronology:

Stathers, R. et al (1988) [1]:

A physically-based numerical model was developed to estimate the temporal course of the surface energy flux densities and the soil temperatures in dry and wet bare soils. Aerodynamic heat, vapour and momentum transfer theory was used to calculate the sensible and latent heat flux densities at the surface under diabatic and adiabatic conditions. A finite-difference solution of the differential equation describing one-dimensional heat transfer was used to calculate the surface soil heat flux density and soil profile temperatures. The surface temperature was determined iteratively by the simultaneous solution of equations describing radiative, heat and momentum transfer at the surface. The model was tested with measurements from energy balance studies conducted on a dry, sandy soil and a wet, silt loam soil, and was found to predict accurately the surface energy fluxes and soil temperatures over three-day periods under conditions of potential and negligible evaporation.

Mihalakakou et al (1992) [2]:

Studied modeling of ground temperatures using measurements over several years and in the other study Mihalakakou obtained various estimated ground temperature profiles and the authors emphasized that ground temperatures are important for geothermal and ground applications.

Mihalakakou et al. (1994) [3]:

This study examines the possibility of the Earth's cooling of pneumatic heat exchangers. The cooling system consists of an underground tube that is placed horizontally where the ambient or internal air is pushed through and cooled by the bulk temperature of the natural earth.

Krarti et al (1995) [4]:

An analytical model is developed to predict the annual variation of soil surface temperature from readily available weather data and soil thermal properties. A parametric analysis is presented to determine the effect of various factors such as evaporation, soil absorptivity, and soil convective properties on soil surface temperature. A comparison of the model predictions with experimental data is presented.

Mihalakakou et al (1997) [5]:

Present a complete model for the prediction of the daily and annual variation of ground surface temperature. The model uses a transient heat conduction differential equation and an energy balance equation at the ground surface to predict the ground surface temperature. The energy balance equation involves the convective energy exchange between air and soil, the solar radiation absorbed by the ground surface, the latent heat flux due to evaporation at the ground surface as well as the long-wave radiation.

Wang J. et al. (1999) [6]:

This paper presents a novel method that allows the diurnal variation of ground heat flux to be computed from the corresponding time series measurement of surface soil temperature. Soil temperature and soil heat flux over time at one location are uniquely related through a half-order derivative/integral operator when heat transfer in a soil matrix is described by a one-dimensional diffusion equation with a constant diffusivity parameter.

Salah el-din (1999) [7]:

Two expressions have been developed to predict the periodic variation of the ground temperature with depth. They are based on the energy balance equation at the ground surface and the assumption that the temperature variation at the ground surface is in the form of a sine-wave or a Fourier series. The energy balance equation involves the periodic variation of solar radiation, atmospheric temperature and the latent heat due to evaporation. A parametric study showed that the ground temperature and the amplitude of the heat into the ground increase with the increasing in the air relative humidity and the ground absorptivity. Conversely, they decrease with the increasing in the evaporation fraction and wind speed. The values of the damping depth is almost the same while the corresponding ground temperature is influenced by the various parameters.

Popiel et al (2001) [8]:

The ground temperature distribution is affected by the structure and physical properties of the ground, the ground surface cover (e.g., bare ground, lawn, snow, etc.) and the climate interaction (i.e., boundary conditions) determined by air temperature, wind, solar radiation, air humidity and rainfall

Richard Allen et al (2002) [9]:

Study explains a remote image-processing model for predicting evapotranspiration ET termed SEBAL (Surface Energy Balance Algorithm for Land). SEBAL calculates evapotranspiration ET through a series of computations that generate: net surface radiation, soil heat flux, and sensible heat flux to the air. By subtracting the soil heat flux and sensible heat flux from the net radiation at the surface, we are left with a “residual” energy flux that is used for evapotranspiration (i.e. energy that is used to convert the liquid water into water vapor). This manual describes the theoretical basis of SEBAL using images from Landsat 5 and 7 satellites. However, the theory is independent of the satellite type and this manual could be applied to other satellite images if used with appropriate coefficients.

Mihalakakou et al. (2002) [10]:

She said that soil temperature is an important parameter in solar energy and geothermal applications such as passive heating and cooling of buildings and greenhouses.

Ogunlela (2003) [11]:

This study modeled the differences of soil temperature. The principles of transit thermal flow were used in the study, assuming that the heat flow was one-dimensional, that the soil was homogeneous and that thermal diffusion was constant. Average conditions are also assumed. Annual and daily soil temperature cycles (daily) are designed with fairly good precision.

Al-Ajmi et al (2006) [12]:

A theoretical model of an earth–air heat exchanger (EAHE) is developed for predicting the outlet air temperature and cooling potential of these devices in a hot, arid climate. The model is validated against other published models and shows good agreement. A sub-soil temperature model adapted for the specific conditions in Kuwait is presented and its output compared with measurements in two locations. The EAHE is shown to have the potential for reducing cooling energy demand in a typical house by 30% over the peak summer season.

Florides et al (2007) [13]:

The ambient climatic conditions affect the temperature profile below the ground surface **(Fig.I.1)** and has to be considered when designing a heat exchanger.

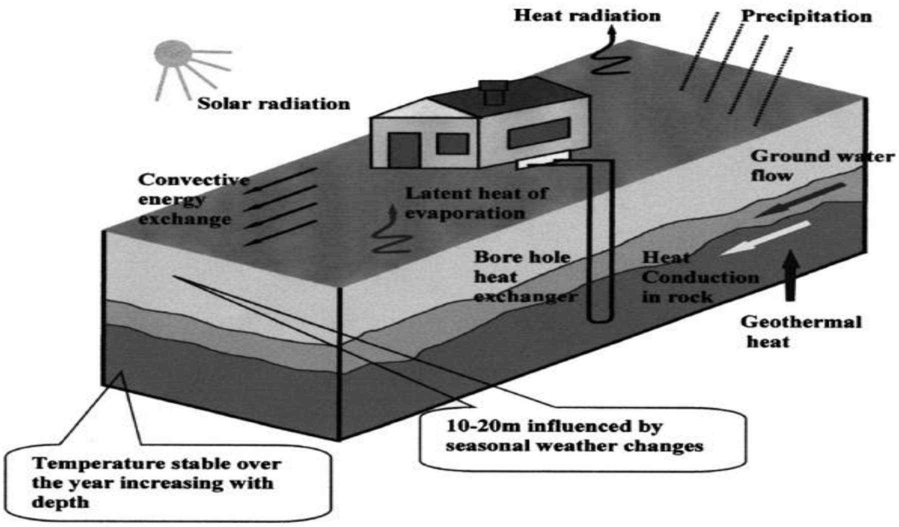


Fig.I.1: Energy flows in ground

Ahmed, A et al (2007) [14]:

Investigated the potential of ground-to-air heat exchangers for cooling buildings with low energy consumption and found that the outlet air temperature decreases with tube depth.

HERB, William R., et al (2008) [15]:

In this study, was used A model for predicting temperature time series for dry and wet land surfaces is described. Surface heat transfer processes on impervious and pervious land surfaces were investigated for both dry and wet weather periods. The surface heat transfer equations were combined with a numerical approximation of the 1-D unsteady heat diffusion equation to calculate pavement and soil temperature profiles to a depth of 10 m. Equations to predict the magnitude of the radiative, convective, conductive and evaporative heat fluxes at a dry or wet surface, using standard climate data as input, were developed.

F. Droulia et al (2009) [16]:

In this work, subsurface ground temperature profiles are estimated by exploiting two different approaches. In the first one, an analytical model is examined which, considering a quasi steady state system, implements the superposition of annual and daily sinusoidal fluctuations. In the second one, semi-empirical models are developed based on the general formula of the preceding, by replacing the steady state soil temperature with easily obtained daily average temperatures. It is concluded that the proposed models may serve as useful tools for estimating and predicting soil temperatures to be used as practical reference in various environmental and energy applications.

Derbel and Kanoun (2010) [17]:

In this paper, an experiment has been conducted in order to record the ground temperature at different depths during 2006 in a suburb of Sfax (Tunisia) which represents an example of the South-Mediterranean climate. The temperature of the soil has also been calculated using a thermal model taking into account properties of the soil and meteorological conditions. Experimental results are compared with theoretical predictions. In order to estimate the influence of the soil properties on the ground temperature, different soil thermal conductivities are tested. A simplified model of an earth pipe system is developed. The cooling and heating capabilities produced by such a system are evaluated. This model is validated against another published experimental model.

Ozgener (2011) [18]:

Study how to predict soil temperatures via geothermal exchange applications. He used a number of data from his experimental ground for the aerial thermal exchange system. According to the experimental study, the authors expressed the relationship between soil and air temperatures. Furthermore, this study contains an association about the soil temperature of capacity

.**Misra et al (2013) [19]:**

Thermal performance of Earth Air Tunnel Heat Exchanger (EATHE) under transient operating conditions has been evaluated for predominantly hot and dry climate of Ajmer (India) using experimental and Computational Fluid Dynamics modeling. Effects of time duration of continuous operation, thermal conductivity of soil pipe diameter and flow velocity on thermal performance of EATHE under transient conditions have been analyzed.

Mabrouki Djamal (2014) [20]:

This work relates to the study of the influence of climatic and environmental parameters as well as their influence on soil temperature. Through numerical modeling, followed by a computer code, we have shown the evolution of the temperature of the ground surface as well as the different heat fluxes exchanged between the ground and the surrounding environment. Finally, they gave the results of an experimental study relating to a Canadian well installed at the University of Biskra.

CLEALL, Peter John et al (2015) [21]:

This work presents analytical solutions for estimating temperature with depth and energy stored within the soil column based on readily available meteorological data, which is of particular interest in the field of geothermal heat extraction and storage. The one-dimensional transient heat diffusion equation with boundary conditions of type II (Newman) in base boundary conditions and type III (Robin), on the basis of heat equilibrium, is solved on the soil surface. In order to describe the interactions between soil and atmosphere, mathematical expressions have been proposed that describe the daily and annual variation of solar radiation and air temperature.

Xamán, J., et al (2015) [22]:

The numerical study of the pseudo transient thermal behavior of an earth-to-air heat exchanger (EAHE) for three cities in México is presented. The climate conditions correspond to the warmest day in summer and the coldest day in winter. The simulations of the EAHE were done in an in-house code based on the finite volume method.

Sedighi, M., et al (2016) [23]:

This study provides a combination of surface boundary conditions related to soil-atmosphere interactions. The state of the frontiers formulated takes into account the heat flow in the soil and atmosphere interface through short-wave radiation mechanisms, long-wave radiation, reasonable radiation and latent thermal radiation. Effects of surface moisture flow on the power balance of the interface are explicitly included in the composition.

Yener et al (2017) [24]:

He theoretically studied the prediction of ground temperatures. The authors estimated ground temperatures at different depths in Izmir/Turkey for heat exchanger applications, e.g. ground-to-air heat exchanger and ground heat exchanger applications, and predicted ground temperature values obtained with continuous ambient air temperature.

Singh and Sharma (2017) [25]:

They studied in this work, the impact of urban surface albedo enhancement in India on regional climate cooling (by using white paint on roofs in India) on radiative forcing and land surface temperature change has been quantified based on the principles of Physics using energy balance equation and one-layer atmospheric model.

Larwa Barbara (2018) [26]:

It was based on a mathematical model based on the heat balance equation on the Earth's surface It has been developed. The basis of the model is the Carslau-Jaeger equation with respect to temperature the profile is in the ground. The model was validated using the experimental results of two different sites (different weather conditions, temperate and dry climate). In this work, many factors affected the Earth's temperature Profiles and heat flow were determined. It was found that among the criteria examined the amplitude of the average daily solar radiation flux strongly influences the total amount of heat transmitted between the land and the environment during the year, where the other parameters have little effect.

Leski Krystian et al (2021) [27]:

In this work, numerical simulation calculations were performed to investigate the minimum ground temperature that occurs when extracting thermal energy in a horizontal ground heat exchanger system in the Central European climate. The influence of ground thermal conductivity, heat flux extracted from the ground, periodic interruptions in the operation of the heat exchanger, periodic supply of heat energy to the ground, relative humidity of the ambient air, evaporation rate coefficient, and convective heat transfer coefficient on the ground minimum temperature were investigated. Based on the simulation, it was found that the high value of ground thermal conductivity favorably affects the operation of the installation with a ground heat exchanger. Both the reduction of the maximum heat flux taken from the ground, as well as periodic interruptions in the operation of the exchanger effectively protects the ground against excessive cooling. Further, it was found that heat supply to the ground in summer only slightly raises its minimum temperature, as well as the decrease of the relative humidity of the ambient air and evaporation rate coefficient. The change of the convective heat transfer coefficient has no significant impact on the minimum annual ground temperature.

I .3. The Works done on (EAHE) systems in Algeria:

Many researchers were interested in studying the geothermal system (EAHE), among them are the following:

Karim DEHINA (2008):

In his memoir of Magister, developed a numerical model in finite differences implemented under the Matlab software of the ground-air exchanger, following a dynamic study of the earth-air exchanger. This one includes a set of parameters intrinsic to the exchanger, and remains expandable to other configurations of physical or geometric order **[28]**.

Djamal SIFODIL (2009):

In his lecture, paper developed a model that studies the thermal behaviour of an air duct buried in the ground. This model evaluates the temperature as a function of the depth in the ground as well as the temperature at the outlet of the duct. The model has been programmed into the MATLAB dynamic simulation tool. Application of the model allowed to determine the factors that influence the earth-to-air exchanger in particular the characteristics of the soil, the nature of the surface, the radiation solar, depth of burial, length, diameter of the duct, flow rate of air in the duct as well as the outside climate **[28]**.

Sehli et al (2012) [29]:

Propose one-dimensional fixed digital model to estimate the performance of heat exchangers from ground to air, Installed on different depth, used for cooling/heating buildings. Two parameters are considered for evaluating the system's performance (Reynolds number and form factor). Numerical It is proposed to process simulation to predict the fluid temperature fields found in the tube and nearby soil Buried tube, taking into account meteorological data of southern Algeria

Mebarki et al (2012) [30]:

As part of this work, an analysis of the performance of the earth’s air exchange was carried out using analytical modelling. They first validated the soil temperature model and the air temperature in the heat exchanger, and then analysed the effect of certain parameters, namely: the depth, diameter and length of the tube on the internal temperature of the heat exchanger.

Hatraf et al (2014) [31]:

Developed a model of a ground-to-air heat exchanger for the building air conditioning. This numerical model, based on the finite differences method, has made it possible to solve the energy equation numerically to obtain the optimal depth to bury the exchanger (three 03 meters for its study case). An experimental study over a one-day (24H) period of the earth-air exchanger on the site of the University of Biskra was conducted to monitor the evolution of the air temperature throughout the exchanger in order to validate the results found by simulation. The study showed the influence of the parameters (depth of burial of the tube, nature of the tube, length of the duct, volume flow) on the performance of the exchanger **[28]**.

Belatrache et al (2017) [32]:

This study provides modelling and simulation of a geothermal air swap (EAHE), used as a conditioning device for buildings in the climatic conditions of southern Algeria. Ground pipes buried in the ground can provide great advantages in terms of energy saving. The proper depth of the buried tubes was calculated taking into account the physical characteristics of the soil in the area under study and using a specific program developed by the authors. Computer analysis was conducted taking into account the length, radius and speed of the tube's air.

Benhammou et al (2017) [33]:

This study aims to verify the impact of thermal insulation on the cooling effectiveness of heat exchange systems from the ground to the atmosphere under the hot and dry climate. Therefore, the dynamic behavior of two identical buildings submitted to the same external petitions equipped with EAHE is presented in detail. To achieve the objective of this study, two transient models have been developed; One to model EAHE and the other to describe the thermal behavior of buildings.

I .4. Conclusion :

For the understanding of the theme, we study the previous works, after which we will begin the Theoretical study.

References :

[1] Stathers, R. J., Black, T. A., Novak, M. D., & Bailey, W. G. (1988). Modelling surface energy fluxes and temperatures in dry and wet bare soils. *Atmosphere-ocean*, *26*(1), 59-73.

[2] Mihalakakou, G., Santamouris, M., & Asimakopoulos, D. (1992). Modelling the earth temperature using multiyear measurements. *Energy and Buildings*, *19*(1), 1-9.

[3] Mihalakakou, G., Santamouris, M., & Asimakopoulos, D. (1994). Modelling the thermal performance of earth-to-air heat exchangers. *Solar energy*, *53*(3), 301-305.

[4] Krarti, M., Lopez-Alonzo, C., Claridge, D. E., & Kreider, J. F. (1995). Analytical model to predict annual soil surface temperature variation

[5] Mihalakakou, G., Santamouris, M., Lewis, J. O., & Asimakopoulos, D. N. (1997). On the application of the energy balance equation to predict ground temperature profiles. *Solar Energy*, *60*(3-4), 181-190.

[6] Wang, J., & Bras, R. L. (1999). Ground heat flux estimated from surface soil temperature. *Journal of hydrology*, *216*(3-4), 214-226.

[7] El-Din, M. S. (1999). On the heat flow into the ground. *Renewable Energy*, *18*(4), 473-490.

[8] Popiel, C. O., Wojtkowiak, J., & Biernacka, B. (2001). Measurements of temperature distribution in ground. *Experimental thermal and fluid science*, *25*(5), 301-309.

[9] Allen, R., Tasumi, M. and Trezza, R. (2002) SEBAL (Surface Energy Balance Algorithms for Land)-Advanced Training and User's Manual-Idaho Implementation, Version 1.0.

[10] Mihalakakou, G. (2002). On estimating soil surface temperature profiles. *Energy and Buildings*, *34*(3), 251-259.

[11] Ogunlela, A. O. (2003). Modeling soil temperature variations. *Journal of Agricultural Research and Development*, *2*(1), 100-109

[12] Al-Ajmi, F., Loveday, D. L., & Hanby, V. I. (2006). The cooling potential of earth–air heat exchangers for domestic buildings in a desert climate. *Building and Environment*, *41*(3), 235-244.

[13] Florides, G., & Kalogirou, S. (2007). Ground heat exchangers—A review of systems, models and applications. *Renewable energy*, *32*(15), 2461-2478.

[14] Ahmed, A., Miller, A., & Ip, K. (2007). The potential of earth-air heat exchangers for low-energy cooling of buildings. *Passive and Low Energy Architecture. National University Singapore, Singapore*.

[15] Herb, W. R., Janke, B., Mohseni, O., & Stefan, H. G. (2008). Ground surface temperature simulation for different land covers. *Journal of Hydrology*, *356*(3-4), 327-343.

[16] Droulia, F., Lykoudis, S., Tsiros, I., Alvertos, N., Akylas, E., & Garofalakis, I. (2009). Ground temperature estimations using simplified analytical and semi-empirical approaches. *Solar Energy*, *83*(2), 211-219.

[17] Derbel, H. B. J., & Kanoun, O. (2010). Investigation of the ground thermal potential in Tunisia focused towards heating and cooling applications. *Applied thermal engineering*, *30*(10), 1091-1100.

[18] Ozgener, L. (2011). A review on the experimental and analytical analysis of earth to air heat exchanger (EAHE) systems in Turkey. *Renewable and sustainable energy reviews*, *15*(9), 4483-4490.

[19] Misra, R., Bansal, V., Agrawal, G. D., Mathur, J., & Aseri, T. K. (2013). CFD analysis based parametric study of derating factor for Earth Air Tunnel Heat Exchanger. *Applied Energy*, *103*, 266-277.

[20] MABROUKI, D. (2014). *Étude de l'influence des paramètres climatiques sur la température du sol (application au site de Biskra)* (Master's thesis).

[21] Cleall, P. J., Muñoz-Criollo, J. J., & Rees, S. W. (2015). Analytical solutions for ground temperature profiles and stored energy using meteorological data. *Transport in Porous Media*, *106*(1), 181-199.

[22] Xamán, J., Hernández-López, I., Alvarado-Juárez, R., Hernández-Pérez, I., Álvarez, G., & Chávez, Y. (2015). Pseudo transient numerical study of an earth-to-air heat exchanger for different climates of México. *Energy and Buildings*, *99*, 273-283.

[23] Sedighi, M., Hepburn, B. D., Thomas, H. R., & Vardon, P. J. (2016). Energy balance at the soil atmospheric interface. *Environmental Geotechnics*, *5*(3), 146-157.

[24] Yener, D., Ozgener, O., & Ozgener, L. (2017). Prediction of soil temperatures for shallow geothermal applications in Turkey. *Renewable and Sustainable Energy Reviews*, *70*, 71-77.

[25] Singh, R. K., & Sharma, R. V. (2017). Numerical analysis for ground temperature variation. *Geothermal Energy*, *5*(1), 1-10.

[26] Larwa, B. (2018). Heat transfer model to predict temperature distribution in the ground. *Energies*, *12*(1), 25.

[27] Leski, K., Luty, P., Gwadera, M., & Larwa, B. (2021). Numerical Analysis of Minimum Ground Temperature for Heat Extraction in Horizontal Ground Heat Exchangers. Energies, 14(17), 5487.

[28] MENHOUDJ, S. (2018). *Intégration des systèmes à énergies renouvelables dans le Bâtiment: Evaluation des performances énergétiques* (Doctoral dissertation, Université Mohamed Boudiaf des Sciences et de la Technologie-Mohamed Boudiaf d'Oran).

[29] Sehli, A., Hasni, A., & Tamali, M. (2012). The potential of earth-air heat exchangers for low energy cooling of buildings in South Algeria. *Energy Procedia*, *18*, 496-506.

[30] Mebarki, B., Draoui, B., Abdessemed, S., Keboucha, A., Drici, S., & Sahli, A. (2012). Etude d'un système de climatisation intégrant un puits canadien dans les zones arides, cas de Béchar. *Journal of Renewable Energies*, *15*(3), 465-478.

[31] Hatraf, N., Chabane, F., Brima, A., Moummi, N., & Moummi, A. (2014). Parametric study of to design an earth to air heat exchanger with experimental validation. *Engineering journal*, *18*(2), 41-54.

[32] Belatrache, D., Bentouba, S., & Bourouis, M. (2017). Numerical analysis of earth air heat exchangers at operating conditions in arid climates. *International journal of hydrogen energy*, *42*(13), 8898-8904.

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

CHAPTER

II

Global warming

And

(EAHE) systems

II.1. Introduction:

Global warming caused the surrounding temperature to increase. To maintain an acceptable thermal comfort in buildings air condition are normally used. In order to provide a cause efficient system, EAHE is proposed to be used. Thermal reduction efficiency of EAHE system highly depend upon the soil in contact with the pipe. Thus, identifying the best soil having excellent thermal dissipation behavior might help in improving the design and performance in EAHE system **[1]**.

II.2. Global warming:

The earth is becoming hotter as global warming occur. Global warming is a problem which happen cause by the everyday activities which require the burning of fossil fuels which result in carbon dioxide emission, one of the major greenhouse gases that causes global warming (Ritzkowski and Stegmann, 2007). The warming of the Earth's is called the greenhouse effect.

There are two type of greenhouse effect which are natural greenhouse effect and the other one is the man-made greenhouse effect. The natural greenhouse effect is the system which keeps the Earth's climate warm and habitable. Different to natural greenhouse, the man-made greenhouse effect is where the enhancement of Earth's natural greenhouse effect by the addition of greenhouse gases from the burning of fossil fuels such as coal and natural gas (Spencer, 2012). The greenhouse gases are include mostly the water vapor clouds, carbon dioxide and methane. Due to human actions from burning of fossil fuels creates more carbon dioxide in atmospheric. The more carbon dioxide, the more infrared energy being trapped and this causes a warming tendency in the lower atmosphere and at the surface. Not only carbon dioxide, many fluorinated gases also have very high global warming potentials relatives to other greenhouse gases, so small atmospheric concentration can have large effects on global temperature. Hydro fluorocarbons comes from major emission source such as air conditioning system in both vehicles and buildings (Lewis, 2011).Spencer R. (2013) stated that as of 2008, it is believed that there is an enhanced of the Earth's natural greenhouse effect by about 1%. The global warming theory also mentioned that the lower atmosphere must had respond to this imbalance where less infrared radiation being lost than solar energy being absorbed by causing an increase in temperature.

According to Natural Resources Defense Council, over the past 50 years the average global temperature has increased at the fastest rate in recorded history and Malaysian Meteorological Department had mentioned that an average temperature increase of 0.5°C to 1.3°C is recorded in Malaysia, when comparing the long term means obtained for 1961- 1990 and 1998-2007. The projected temperature increase in the next 30 years is between 1.0°C to 3.5°C. Increases of greenhouse gases such as carbon dioxide in the atmosphere claims to be one of the reasons of rising atmosphere temperature.

Under this global warming, alternative solutions must be considered for cooling systems, including the Ground Air Heat Swap (EAHE), which has shown to provide an effective and economical approach to reducing the temperature of the interior building as well as reducing electricity consumption and carbon dioxide emissions. As a ground pairing, EAHE is designed to indirectly cool or heat buildings by ventilating outdoor air through a series or series of underground-buried pipes. The efficiency of EAHE systems depends on several factors, namely the type of pipe, metal fixtures and thermal conductivity of the surrounding soil **[1]**.

II.3. Overview of Earth-to-Air Heat Exchangers systems (EAHE):

II.3.1. definition:

The Earth-to-Air Heat Exchanger, commonly called "Canadian wells", "climate wells" or "Provencal wells", is a semi-passive system that exploits the ground's geothermal energy, knowing that at a depth of 2.5 m it has a near constant temperature. This exchanger (whose concept is very old, 3000 BC) is now widely used in the residential and agricultural sectors to control the temperature of buildings. Air-to-ground heat exchangers are currently listed worldwide as one of the most dynamic systems in the field of renewable energy, with an annual increase of 10% (over the last 10 years) in the number of installations in nearly 30 countries **[2]**.

II.3.2. Operating principle:

The Canadian well is a system used to temper the air intakes used for the ventilation of buildings. This system can be used for any type of building, whether residential, tertiary or agricultural. The idea is to pass the new outside air through an underground duct in order to bring its temperature closer to that of the basement, which is **(Fig .II.1)** shows the operating principle of Canadian wells.

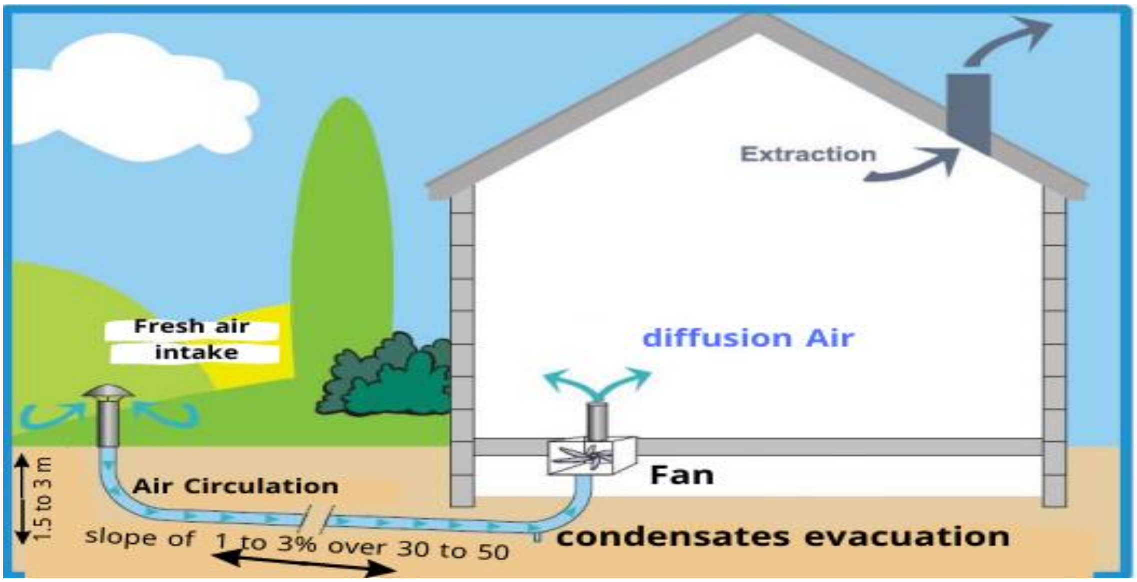


Fig .II.1: Simplified diagram of a single-tube Canadian well **[2]**.

II.3.3. Operating modes of an air-ground exchanger:

It is the physical laws of thermal inertia of the soil and heat transfer that allow estimating the temperature level at the outlet of the buried sheath. The principle is to passively use geothermal energy. Generally, the system is reversible. In Winter, fresh outside air is heated or preheated from the ground through the duct buried. In Summer the warm air outside is cooled in the same way. This allows to saving energy in both Summer and Winter **[2]**.

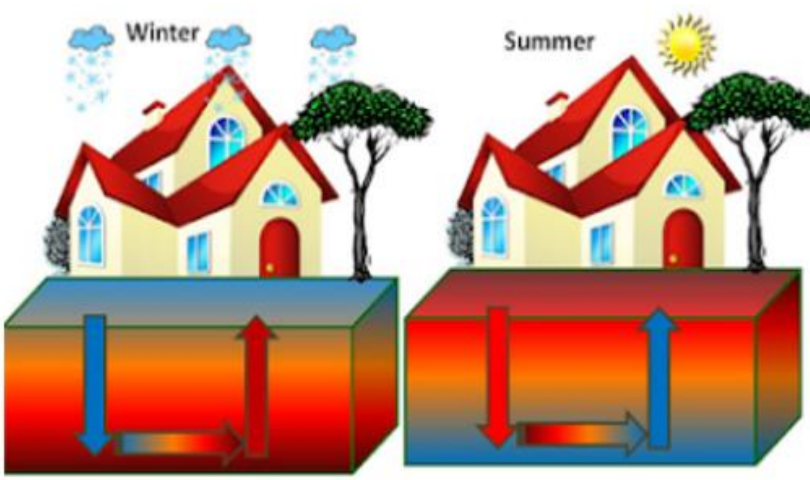


Fig.II.2: Canadian well in Winter and Summer **[3]**.

- **In Winter:**

In winter at a certain depth, the soil temperature is below the external temperature of the air, and this difference is exploited in order to heat the air and bring it into the building allowing the provision of heating by up to 15% depending on the areas.

- **In Summer:**

In winter at a certain depth, the soil temperature is more than the external temperature of the air, and this difference is exploited in order to heat the air and bring it into the building, allow the cooling of ambient air without the use of the air conditioning system and abandon conventional air conditioning due to the environmental damage (ozone layer, greenhouse gases) and the benefits obtained that make it possible to obtain acceptable living conditions and healthy accommodation.

II.3.4. Types:

There are two different types of air-ground heat exchangers. The first, with an "open loop" where the outside air is drawn through tubes to ventilate the room, and the second with a "closed loop" where the air is drawn from the room before being recycled through the tubes. The latter type is less used in the residential sector because it does not meet the requirements of air quality. The important aspects that determine the efficiency of an air-sol exchanger are the nature of the climate, the thermo-physical properties of the soil, the depth of the rock this information is essential for the dimensioning of the air-ground heat exchanger system. **[2]**, Shows in **(Fig.II.3)**.

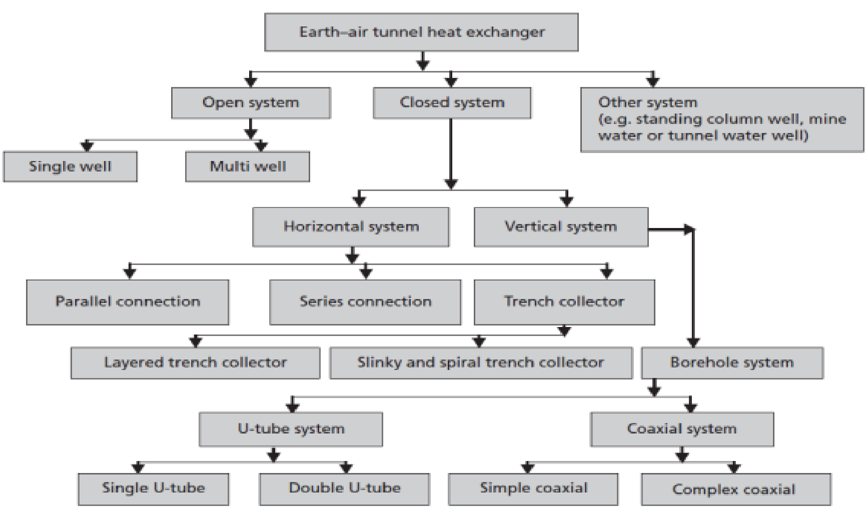


Fig.II.3: Classification of earth to air heat exchanger **[4]**.

II.3.4.a. Open systems:

In open systems, ambient air passes through tubes buried in the ground for pre-heating or pre-cooling and then the air is heated or cooled by a conventional air conditioning unit before entering the building Shows in **(Fig.II.4).**

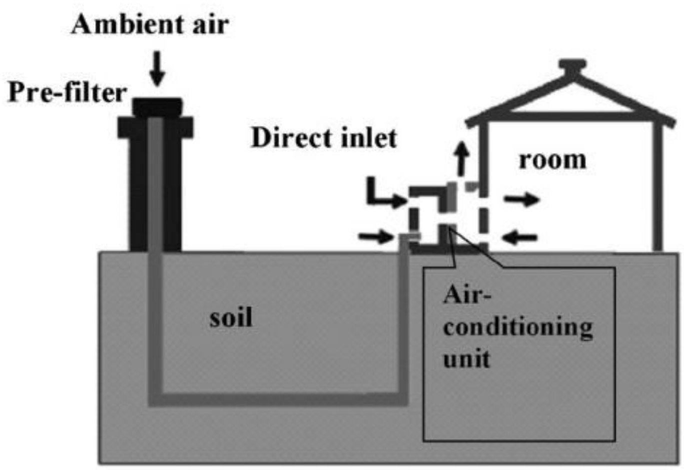


Fig.II.4: Basic principle of ground preheating or pre-cooling of air in an open system **[5]**.

II.3.4.b. Closed systems:

The horizontal type which has a number of pipes connected together either in series or in parallel is usually the most cost-effective when adequate yard space is available and trenches are easy to dig, see **(Fig.II.5)** . The trenchers have a depth of 1–2 m in the ground and usually a series of parallel plastic pipes is used. Fluid runs through the pipes in a closed system. A typical horizontal loop is 35–60 m long per kW of heating or cooling capacity. Horizontal ground loops are the easiest to install while a building is under construction. However, new types of digging equipment allow horizontal boring and thus it is possible to retrofit such systems into existing houses with minimal disturbance of the topsoil and even allow loops to be installed under existing buildings or driveways. the pipe is curled into a slinky shape **(Fig.II.6).** In this way, it is possible to place more pipes into shorter trenches in order to reduce the amount of land space needed .These collectors are best suited for heating and cooling in places where natural temperature recharge of the ground is not vital.

For all horizontal systems in heating-only mode, the main thermal recharge is provided by the solar radiation falling on the earth surface. Therefore, it is important not to cover the surface above the ground heat collector

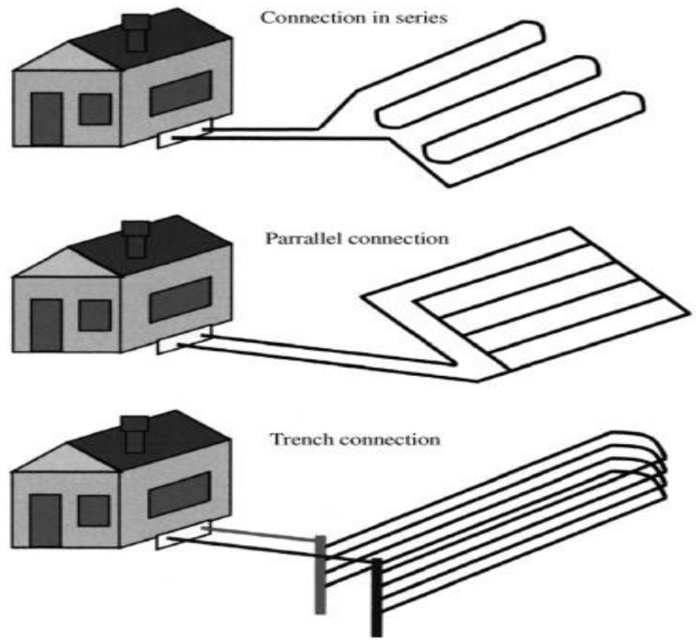


Fig.II.5: Horizontal-type ground heat exchangers **[5]**.

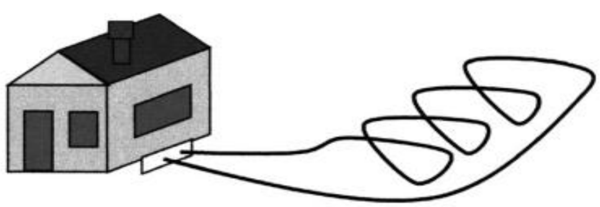


Fig.II.6:‘‘Slinky’’type ground heat exchanger **[5]**.

Vertical ground heat exchangers or borehole heat exchangers, shown in **(Fig.II.7)**, are widely used when there is a need to install sufficient heat exchange capacity under a confined surface area such as when the earth is rocky close to the surface, or where minimum disruption of the landscape is desired. Vertical loops are generally more expensive to install, but require less piping than horizontal loops because the earth deeper down is cooler in summer and warmer in winter, compared to the ambient air temperature **[5]**.

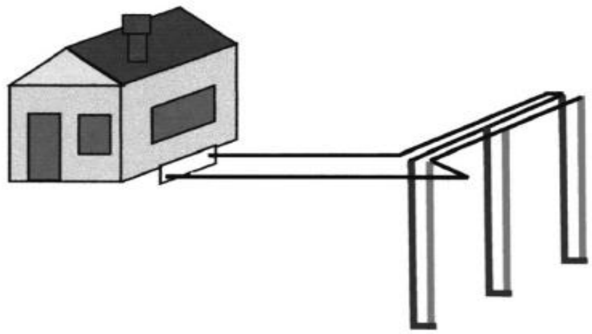


Fig.II.7: Vertical ground heat exchangers **[5]**.

II.3.5. Location:

Three ways of installing the air-ground exchanger are possible:

1- Under the building

2- In the excavations of the building

3- In the field

Technically, these variants are equivalent, the difference is in terms of costs of earthworks, the second variant being the most interesting financially, none additional earthworks not to be carried out. During the installation of the pipes, it is necessary **[6]**.

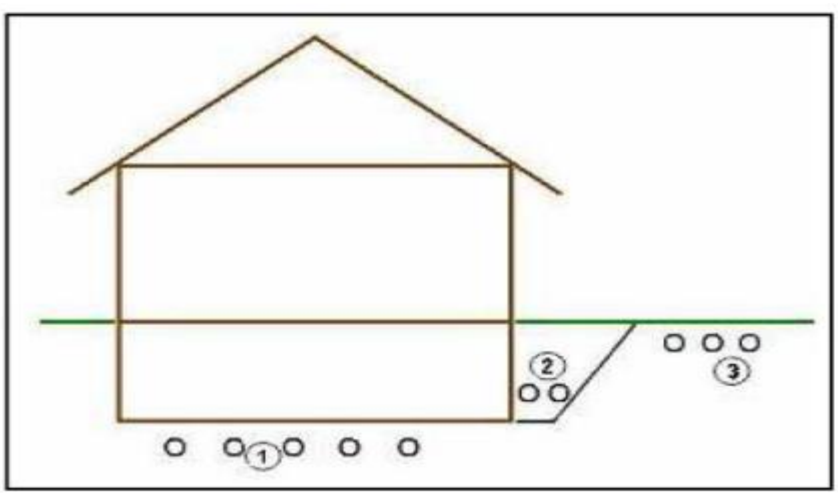


Fig.II.8: Location the air-ground exchanger **[6]**.

II.3.6. Advantages:

The main advantages of the air-ground exchanger system are its technical simplicity, its great cooling and preheating potential and also its low capital costs, operation and maintenance in addition to energy saving and the limitation of greenhouse gases.

II.3.7. Analysis of various parameters:

Analysis of the literature consulted has made it possible to identify the parameters influencing the thermal behaviour of the air-ground heat exchanger and to distinguish the most important ones. These parameters are considered for the dimensioning of an air-ground exchanger.

The selection criteria for tubes are based on mechanical strength, durability, sealing, thermal conductivity and impermeability. The Canadian well can be constructed a single tube loop or multiple tubes mounted in parallel. The configuration of the tube network depends on the size of the available surface. The walls of the tubes are treated to reduce microbial growth that can pollute fresh air. Studies on air pollution have been carried out and have shown that the concentration of a possible growth of harmful bacteria could even be reduced due to the flow of air. The sizing of a Canadian well is quite tricky because of the number of parameters to be optimized: length, diameter and number of tubes, depth of burial, distance between tubes, ventilation flow rate and building temperature **[3]**.

- **Soil type:**

Thevenard (2007) reported that wet soil is preferable to dry soil because of better thermal conductivity; peat and dry sand should be avoided. The author suggest surrounding the pipes with compacted clay to ensure good thermal contact between the pipes and the earth.

Ascione et al. (2011) found that the best energy performances have been obtained for wet and heavy soil. As regards the material surrounding the buried tube, a good contact between soil and tubes has to be ensured, by means of compacted clay or sand. These kinds of soil are also suitable for a correct tube installation **[4]**.

- **Tube length:**

The length of the Canadian well tubes determines the exchange surface and the residence time of the air in the tubes. Several studies have shown that, below 25 metres in length, the Canadian well does not produce an outlet temperature close to that of the soil, because the exchange rate is average. On the other hand, over 40 meters the efficiency no longer increases significantly. It is preferable to use several tubes of reasonable length (20 m to 40 m) rather than one tube of length. Note that the longer the tube, the greater the load losses resulting in a greater energy consumption per fan **[2]**.

- **Airflow:**

The airflow in the tubes occurs simultaneously on the convective exchange between air and piping and on the thermal power supplied to the building. An optimum is to be determined; the overall flow rate must correspond mainly to the air renewal needs of the room or area to be ventilated. During summer cooling, the flow rate should be higher only during winter preheating where only hygienic flow is required **[2]**.

- **Tube material :**

Ascione et al. (2011) found that concrete, plastic or metallic materials lead to very similar energy performances. In fact, due to the small thickness of the tubes (5 mm in the case of PVC, 7 mm for the metallic material, 7 cm for the concrete), the different thermal conductivity values scarcely influence the heat exchange, if the right depths and lengths are used. Note that the concrete tubes require a further internal coating to avoid possible radon infiltrations; furthermore, hygienic conditions inside the tubes must be assured, for example by using antimicrobial coatings. Finally the tube material (usually, PVC, metal or concrete) on the energy performance is negligible **[4]**.

- **Air velocity :**

Ascione et al. (2011) concluded that low speeds (about 8 m/s) of the airflow inside the tubes are preferable, as the pressure drops and fan electric energy requirements decrease.

Lee and Strand (2008) and Lee and Strand (2006) indicated that an earth tube with a lower air velocity will perform better since the air spends more time in the tube and thus in contact with the lower soil temperature.

Abdullahi et al. (2007) found that the pipe outlet temperature increases with increased air velocity. Mihalakakou et al. (1996) investigated the impact of air speed on the thermal behavior of the system (buried pipes techniques). The overall analysis demonstrated that a higher air velocity leads to a slight decrease of air temperature at the pipe exit and then to a reduction of the system's heating capacity. Santamouris et al. (1995) found that the greenhouse indoor air temperature increases with increasing air velocity inside the pipes **[4]**.

- **Outlet temperature:**

The outlet temperature of a buried tube is directly related to the temperature of the ground, its amplitude decreases strongly with the depth.

The tube must therefore be buried sufficiently in order to make the most of the soil's inertia. The type of soil does not important on the outlet temperature in the case of an air-ground heat exchanger consisting of one tube, provided that the flow rate is not too high. (Woodson 2012) presented a case study to examine the soil temperature gradient and (**EAHE**) yield in Burkina Faso. Experiments have been carried out at the depth of burial of 0.5 m, 1.0 m and 1.5 m. He concluded that the decrease in outside temperature of about 7.6°C is achieved with a 25 m long tube buried at a depth of 1.5 m and equipped with a capacity fan of 95 m3/h. The subsoil temperature recorded low values at the time the outside temperature was highest **[2]**.

- **Tube diameter:**

The number and diameter of the tubes define the total section of tubes through which the air will circulate, affecting both the velocity of the airflow and the surface of contact between the air and the ground. The small diameter tubes give a better thermal performance, but with significant pressure drops (De Paepe & Janssens 2003); the diameter of the tube and the airflow are linked by the velocity of the air flowing through the tube.

This should not exceed 3 metres per second so as not to induce significant load losses in the tube. The quality of the exchange varies little depending on the diameter, In order to obtain a significant flow rate; it must be between 15 and 25 centimetres (De Paepe & Janssens 2003). The ventilation regime may vary depending on the mode of operation (reduced in preheating, higher in cooling). The greater the flow rate, the greater the length of the tube **[2]**.

- **Distance between tubes :**

The distance between the tubes is also very important because it affects the temperature of the portion of the ground between these tubes, which locally reduces the soil storage. According to (Hollmuller 2002) a distance of 40 cm will be sufficient to maintain the thermal storage effect for daily variations. On the other hand, a Seasonal thermal storage would require a spacing of about 3 m, which is generally not feasible in practice. In any case, if several tubes are placed at Proximity must be sufficiently spaced so that the soil can regenerate **[2]**.

- **The depth of burial :**

The depth of burial affects the quality of the insulation between the atmosphere and the buried tubes. The calculation of the burial depth depends on the nature of the soil (thermal conductivity, thermal diffusivity, and thermal capacity) and heat exchange between the surface of the ground and the surroundings: by radiation with the sun and the sky and by convection with the ambient air. (Hollmuller 2002) shows that variations in the temperature of the outside air are all the more dampened and out of phase by the ground as the depth is great **[3]**.

II.4. Conclusion:

In this chapter, we presented the global warming, EAHE systems and global environmental for the contribution to the rationalization of the energy consumption of buildings, and to the minimisation of their greenhouse gas emissions, many technical alternatives have been explored. One of these techniques is the air-ground exchanger, the principle of which is technically simple. The principle of cooling with air-to-ground heat exchangers is well established, but the behaviour of such a system depends on climatic conditions and nature of the soil. The dynamic thermal behaviour of an air-ground heat exchanger is therefore not universal and must be studied in the context of climate, soil and building load conditions. In this first chapter, we have presented a literature review of the work done on air-ground exchangers worldwide and in particular, in Algeria, as well as the results of each study.

Reference:

[1] Nor'aini, N. A. M. (2014). *Effect of Different Type of Soil in Efficiency of Thermal Reduction in Earth Air Heat Exchanger (EAHE)* (Doctoral dissertation, UMP).

[2] Khabbaz, M. (2016). *Contribution à l'étude d'un échangeur de chaleur air-sol (puits canadien) pour le rafraîchissement de l'air sous le climat chaud et semi-aride de Marrakech* (Doctoral dissertation, Université de La Rochelle).

[3] https://e-learning-re.blogspot.com/2015/06/heat-pump.html seen in10/04/2022.

[4] Gouda, A. (2010). Using of geothermal energy in heating and cooling of agricultural structures. *Benha University*.

[5] Florides, G., & Kalogirou, S. (2007). Ground heat exchangers—A review of systems, models and applications. *Renewable energy*, *32*(15), 2461-2478.

[6] B. Mohammed et T. Abderrahmane, Dimensionnement et analyse de fonctionnement d'un échangeur air-sol, Mémoire d'Ingénieur, Université Kasdi Merbah, Ouargla, (2010).

CHAPTER

III

Theoretical Study

III.1. Introduction:

The environmental parameters responsible for the distribution of the Earth's surface temperature such as (flux of net radiation, conductive flux in the soil, latent heat and convective flux, convective heat transfer, wind speed, vegetation and land surface cover) see **(Fig III .1)** , are those that affect the Earth's temperature and the Earth's heat transfer rate due to The exchange between the atmosphere and the soil surface can be divided into three main categories: climatic variables, land surface variables, and soil basic variables. In fact, these effects are mainly determined by the climatic conditions of the area such as insolation, air temperature and precipitation. Each area of the soil that is particularly affected is characterized by periodic changes in air temperature and solar radiation, which occur due to seasonal and daily fluctuations and other meteorological factors such as wind, rain and humidity must be taken into account. This is also due to the physical properties that characterize the nature of the soil (thermal conductivity, heat capacity, water content, etc.). This helps greatly in energy applications, civil engineering and agriculture (greenhouse heat balance).

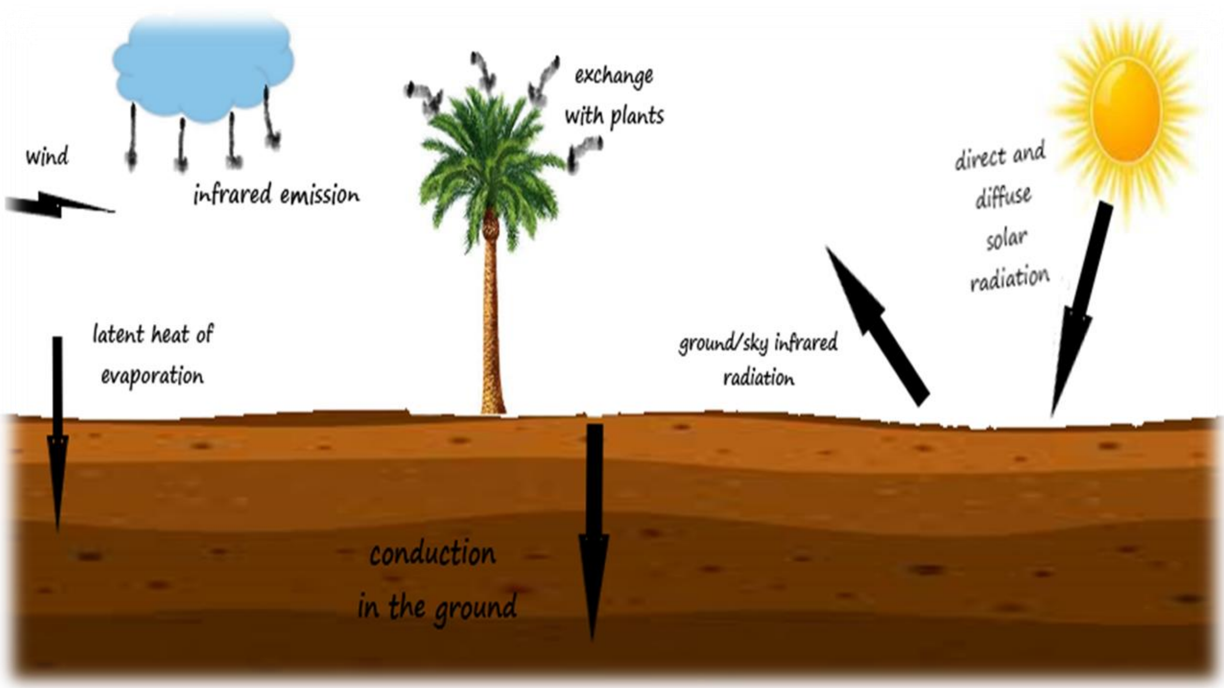


Fig.III.1: Major mechanisms of energy exchange at the soil–atmosphere interface.

III.2. Brief review on heat transfer modes: [1], [2]:

A simple, yet general, definition provides sufficient response to the question: What is heat transfer?

Heat transfer (or heat) is thermal energy in transit due to a spatial temperature difference.

Whenever there exists a temperature difference in a medium or between media, heat transfer must occur.

As shown in **(Fig.III.2)**, we refer to different types of heat transfer processes as modes. When a temperature gradient exists in a stationary medium, which may be a solid or a fluid, we use the term conduction to refer to the heat transfer that will occur across the medium. In contrast, the term convection refers to heat transfer that will occur between a surface and a moving fluid when they are at different temperatures. The third mode of heat transfer is termed thermal radiation. All surfaces of finite temperature emit energy in the form of electromagnetic waves. Hence, in the absence of an intervening medium, there is net heat transfer by radiation between two surfaces at different temperatures.

The transfer of energy as heat is always from the higher-temperature medium to the **l**ower-temperature one, and heat transfer stops when the two mediums reach the same temperature.

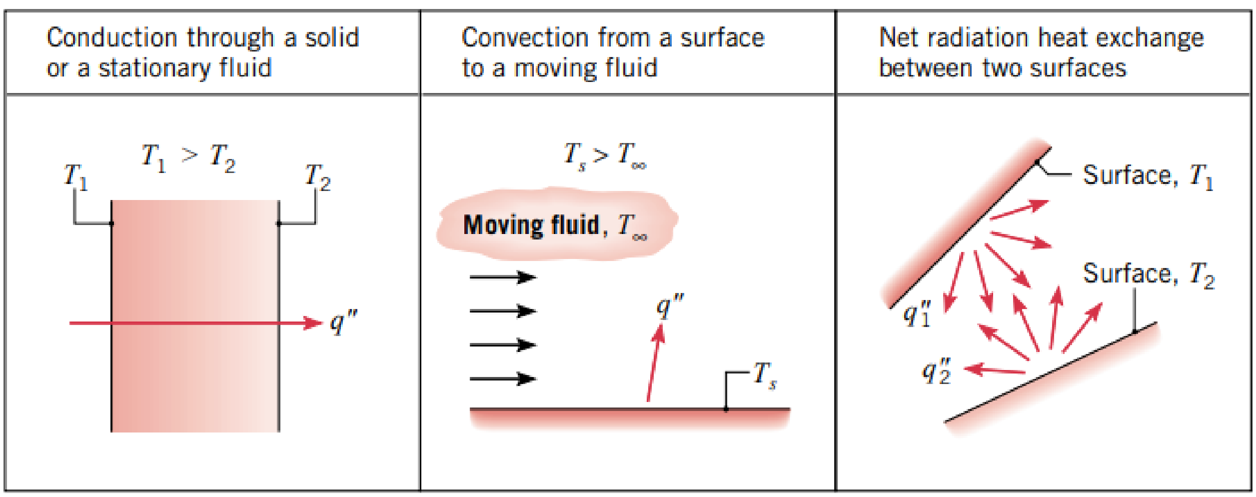


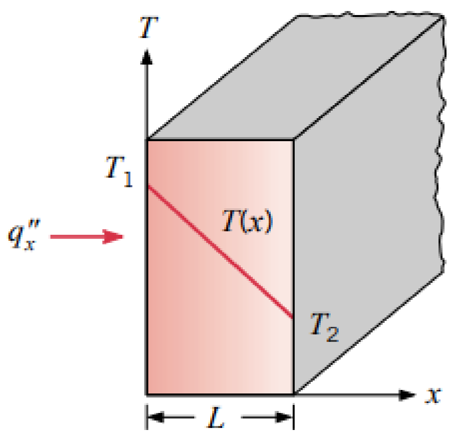
Fig III.2: Conduction, convection, and radiation heat transfer modes **[1]**.

III.2.1. Conduction:

Conduction may be viewed as the transfer of energy from the more energetic to the less energetic particles of a substance due to interactions between the particles.

It is possible to quantify heat transfer processes in terms of appropriate rate equations. These equations may be used to compute the amount of energy being transferred per unit time. For heat conduction, the rate equation is known as Fourier's law. For the one-dimensional plane wall shown in **(Fig.III.3),** having a temperature distribution T(x), the rate equation is expressed as:

$$q''_x = -\lambda \frac{dT}{dx} \qquad \text{(III.1)}$$



q''_x **(W/m²):** is the heat transfer rate in the x direction per unit area,

$\frac{dT}{dx}$ **(K/m)**: is the temperature gradient, and

λ **(W/m·K):** is a transport property known as the thermal conductivity and is a characteristic of the material.

Fig.III.3: One-dimensional heat transfer by conduction (diffusion of energy) **[1]**.

The minus sign is a consequence of the fact that heat is transferred in the direction of decreasing temperature. Under the steady-state conditions shown in **(Fig.III.3)**. Where the temperature distribution is linear, the temperature gradient and the heat flux is then may be expressed as:

$$q''_x = -\lambda \frac{T_2 - T_1}{L} = -\lambda \frac{\Delta T}{L} \qquad \text{(III.2)}$$

III.2.2. Convection :

Convection is the mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, and it involves the combined effects of conduction and fluid motion. The faster the fluid motion, the greater the convection heat transfer. In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction. The presence of bulk motion of the fluid enhances the heat transfer between the solid surface and the fluid, but it also complicates the determination of heat transfer rates. Consider the cooling of a heated surface by blowing cool air over its top surface **(Fig.III.4)**. Heat is first transferred to the air layer adjacent to the surface by conduction. This heat is then carried away from the surface by convection, that is, by the combined effects of conduction within the air that is due to random motion of air molecules and the bulk or macroscopic motion of the air that removes the heated air near the surface and replaces it by the cooler air.

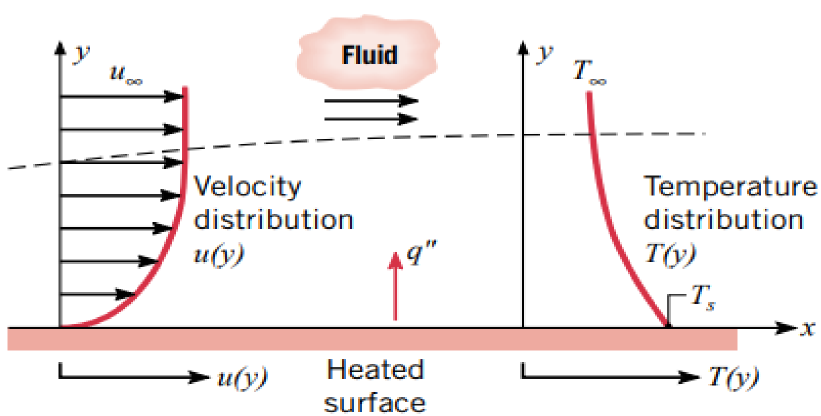


Fig.III.4: Boundary layer development in convection heat transfer **[1]**.

Convection is called forced convection if the fluid is forced to flow over the surface by external means such as a fan, pump, or the wind **(Fig.III.5.a)**. In contrast, convection is called natural (or free) convection if the fluid motion is caused by buoyancy forces that are induced by density differences due to the variation of temperature in the fluid **(Fig.III.5.b)**. For example, in the absence of a fan, heat transfer from the surface in **(Fig.III.4)** is by natural convection since any motion in the air in this case is due to the rise of the warmer (and thus lighter) air near the surface and the fall of the cooler (and thus heavier) air to fill its place. Heat transfer between the block and the surrounding air is by conduction if the temperature difference between the air and the block is not large enough to overcome the resistance of air to movement and thus to initiate natural convection currents.

We have described the convection heat transfer mode as energy transfer occurring within a fluid due to the combined effects of conduction and bulk fluid motion. Typically, the energy that is being transferred is the sensible or internal thermal, energy of the fluid. However, there are convection processes for which there is, in addition, latent heat exchange. This latent heat exchange is generally associated with a phase change between the liquid and vapor states of the fluid. Two special cases of interest in this text are boiling and condensation. For example, convection heat transfer results from fluid motion induced by vapor bubbles generated at the bottom of a pan of boiling water **(Fig.III.5.c)** or by the condensation of water vapor on the outer surface of a cold water pipe **(Fig.III.5.d)**.

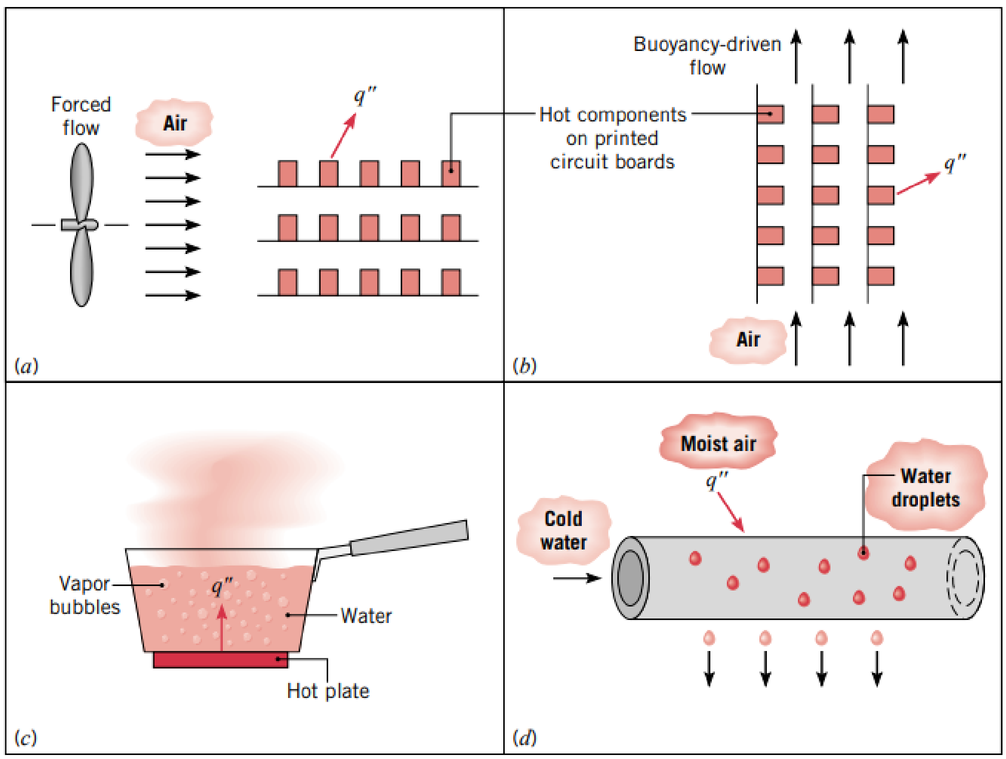


Fig.III.5: Convection heat transfer processes. **(a)** Forced convection. **(b)** Natural convection. **(c)** Boiling. **(d)** Condensation **[1]**.

Despite the complexity of convection, the rate of convection heat transfer is observed to be proportional to the temperature difference, and is conveniently expressed by Newton's law of cooling as:

$$q'' = h(T_s - T_\infty) \qquad \textbf{(III.3.a)}$$

q'' (**W/m²**): is the convective heat flux,

T_s, T_∞ **(K):** are the surface and fluid temperatures respectively, and

h **(W/m²·K)**: is the convection heat transfer coefficient and it depends on conditions in the boundary layer, which are influenced by surface geometry, the nature of the fluid motion, and an assortment of fluid thermodynamic and transport properties.

When Equation 1.a is used, the convection heat flux is presumed to be positive if heat is transferred from the surface ($T_s > T_\infty$) and negative if heat is transferred to the surface ($T_\infty > T_s$). However, if ($T_\infty > T_s$), there is nothing to preclude us from expressing Newton's law of cooling as:

$$q'' = h(T_\infty - T_s) \qquad \textbf{(III.3.b)}$$

In which case heat transfer is positive if it is to the surface.

III.2.3. Radiation:

Radiation is the energy emitted by matter in the form of electromagnetic waves (or photons) as a result of the changes in the electronic configurations of the atoms or molecules. Unlike conduction and convection, the transfer of heat by radiation does not require the presence of an intervening medium. In fact, heat transfer by radiation is fastest (at the speed of light) and it suffers no attenuation in a vacuum. This is how the energy of the sun reaches the earth. In heat transfer studies, we are interested in thermal radiation, which is the form of radiation emitted by bodies because of their temperature. It differs from other forms of electromagnetic radiation such as x-rays, gamma rays, microwaves, radio waves, and television waves that are not related to temperature. All bodies at a temperature above absolute zero emit thermal radiation. Radiation is a volumetric phenomenon, and all solids, liquids, and gases emit, absorb, or transmit radiation to varying degrees. However, radiation is usually considered to be a surface phenomenon for solids that are opaque to thermal radiation such as metals, wood, rocks since the radiation emitted by the interior regions of such material can never reach the surface, and the radiation incident on such bodies is usually absorbed within a few microns from the surface.

Consider radiation transfer processes for the surface of **(Fig.III.6).** Radiation that is emitted by the surface originates from the thermal energy of matter bounded by the surface, and the rate at which energy is released per unit area (W/m²) is termed the surface emissive power E. There is an upper limit to the emissive power, which is prescribed by the Stefan–Boltzmann law

$$E_b = \sigma {T_s}^4 \qquad \textbf{(III.4)}$$

T_s**(K):** is the absolute temperature of the surface, and

(**σ=5.67 W/m²·K⁴)** is the **Stefan– Boltzmann constant**. Such a surface is called an **ideal radiator** or **blackbody**.

The heat flux emitted by **a real surface** is less than that of a **blackbody** at the same temperature and is given by

$$E = \varepsilon\sigma T_S^4 \qquad \textbf{(III.5)}$$

Where ε is the **emissivity** of the surface.

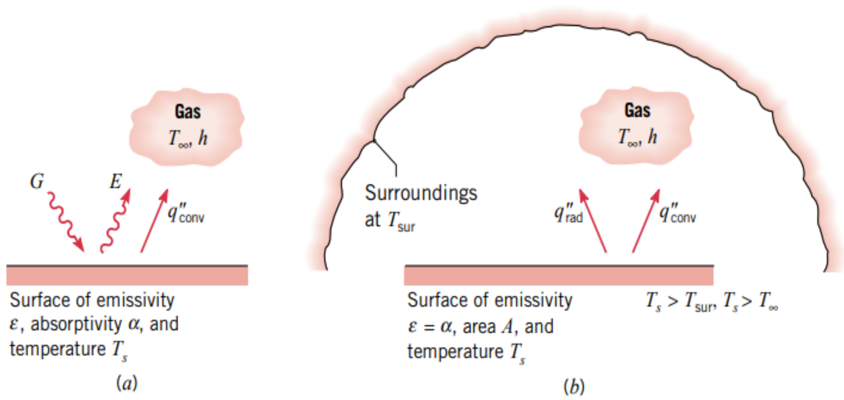


Fig.III.6: Radiation exchange, **(a)** at a surface and **(b)** between a surface and large surroundings **[1]**.

The property emissivity, whose value is in the range $\leq \boldsymbol{\varepsilon} \leq \mathbf{1}$, is a measure of how closely a surface approximates a blackbody for which $\boldsymbol{\varepsilon} = \mathbf{1}$.

Another important radiation property of a surface is its **absorptivity α**, which is the fraction of the radiation energy incident on a surface that is absorbed by the surface. Like emissivity, its value is in the range $\mathbf{0} \leq \boldsymbol{\alpha} \leq \mathbf{1}$. A blackbody absorbs the entire radiation incident on it. That is, a blackbody is a perfect absorber ($\boldsymbol{\alpha} = \mathbf{1}$) as it is a perfect emitter.

Radiation may also be incident on a surface from its surroundings. The radiation may originate from a special source, such as the sun, or from other surfaces to which the surface of interest is exposed. Irrespective of the source, we designate the rate at which all such radiation is incident on a unit area of the surface as the irradiation G (**Fig. II.6.a)**.

$$G_{abs} = \alpha G$$

In general, both $\boldsymbol{\varepsilon}$ and $\boldsymbol{\alpha}$ of a surface depend on the temperature and the wavelength of the radiation. Kirchhoff's law of radiation states that the emissivity and the absorptivity of a surface at a given temperature and wavelength are equal. In many practical applications, the surface temperature and the temperature of the source of incident radiation are of the same order of magnitude, and the average absorptivity of a surface is taken to be equal to its average emissivity.

When a surface of emissivity $\boldsymbol{\varepsilon}$ and surface area $\boldsymbol{A}$, at a thermodynamic temperature $\boldsymbol{T_s}$ is completely enclosed by a much larger (or black) surface at thermodynamic temperature $\boldsymbol{T_{sur}}$, in which case $\boldsymbol{G = \sigma T_{sur}^4}$, separated by a gas (such as air) that does not intervene with radiation, the net rate of radiation heat transfer between these two surfaces is given by **(Fig.III.6.b)**

$$q''_{rad} = \frac{q_{rad}}{A} = \varepsilon E_b(T_s) - \alpha G(T_{sur}) = \varepsilon\sigma(T_s^4 - T_{sur}^4) \qquad \textbf{(III.7)}$$

This expression provides the difference between thermal energy that is released due to radiation emission and that, which is gained due to radiation absorption.

There are many applications for which it is convenient to express the net radiation heat exchange in the form

$$q_{rad} = h_r A(T_s - T_{sur}) \qquad \textbf{(III.8)}$$

Where, from Equation **II.7**, the radiation heat transfer coefficient $\boldsymbol{h_r}$,is

$$h_r = \varepsilon\sigma(T_s + T_{sur})(T_s^2 + T_{sur}^2) \qquad \textbf{(III.9)}$$

Here we have modeled the radiation mode in a manner similar to convection. In this sense we have linearized the radiation rate equation, making the heat rate proportional to a temperature difference rather than to the difference between two temperatures to the fourth power. Note, however, that ($\boldsymbol{h_r}$) depends strongly on temperature, while the temperature dependence of the convection heat transfer coefficient h is generally weak.

The surfaces of **(Fig.III.6)** may also simultaneously transfer heat by convection to an adjoining gas. For the conditions of **(Fig.III.6.b)**, the total rate of heat transfer from the surface is then:

$$q = q_{con} + q_{rad} = hA(T_\infty - T_s) + \varepsilon A\sigma(T_s^4 - T_{sur}^4) \qquad \textbf{(III.10)}$$

III.3. Ground properties:

III.3.1. Thermal conductivity:

The thermal conductivity of a soil depends not only on its composition but also on the arrangement and shape of its constituent particles, the bonds between these particles and their water content. The soil will be more conductive to heat as it will be damp.

III.3.2. Heat capacity:

The calorific capacity of a soil is expressed by the weighted average of the capacities of its constituents: minerals, organic matter, water, air. **Table.III.1** shows the thermophysical properties of different types of soil**:**

Soil type	ρ (kg/m^3)	λ (W/m.K)	Cp (J/kg.K)
Wet sand	1750	0.58	1000
Clay	1450	1.25	880
clay-sand silt	1800	1.5	1340

Table.III.1: Thermophysical properties of various soil types **[3]**.

III.3.3. Thermal diffusivity:

Soil thermal properties, including thermal conductivity, heat capacity, and thermal diffusivity, play an important role in the surface energy partitioning and resulting temperature distribution. The performance of an earth to air heat exchanger (EAHE) is directly related to the thermal properties of the ground. The ground has thermal properties that give it a high thermal inertia. The heat transfer mechanisms in soils are, in order of importance: conduction, convection and radiation. Conduction occurs throughout the soil but the main flow of heat is through the solid and liquid constituents. Convection is usually negligible, with the exception of rapid water infiltration after irrigation or heavy rain. Radiation is important only in very dry soils, with large pores, when the temperature is high. Therefore, the main parameters influencing the thermal behavior of the soil are the thermal conductivity and heat capacity, which can be jointly expressed under the term of thermal diffusivity:

$$\alpha_{soil} = \frac{\lambda_{soil}}{\rho_{soil} C_{soil}}$$

Where, (α_{soil}) is the thermal diffusivity (**m²/s**), (λ_{soil}) is the thermal conductivity (**W/m. °C**), (ρ_s) is the density (**kg/m³**) and (Cp_{soil}) is the specific heat of the soil **(J/kg. °C**).

Soil type	ρ (kg/m³)	λ (W/m.K)	Cp (J/kg.K)	α (m²/s)
Gravelly sand	2800	1.7	1860	3.264×10^{-7}
Sandy loam	2300	2.01	1380	6.333×10^{-7}
Sandy	2525	3.12	930	13.286×10^{-7}

Table.III.2: Thermophysical properties of the various soil type **[11]**.

Thermal diffusivity determines the thermal behavior of the soil. The temperature field in the ground depends on the soil type and the moisture contained, respectively. In most cases, there is no detailed information about soil characteristics available and the moisture varies throughout the year (Zhao, 2004). However, **(ASHRAE, 2011)** gives the thermal properties of selected soils, rocks, and backfills as shown in **(Table.III.3) [4]**.

	Dry density (kg /m³)	Conductivity (W/m.K)	Diffusivity (m²/day)
Soils			
Heavy clay, 15% water	1925	1.4 to 1.9	0.042 to 0.061
Heavy clay, 5% water	1925	1.0 to 1.4	0.047 to 0.061
Light clay, 15% water	1285	0.7 to 1.0	0.055 to 0.047
Light clay, 5% water	1285	0.5 to 0.9	0.056 to 0.056
Heavy sand, 15% water	1925	2.8 to 3.8	0.084 to 0.1 1
Light sand, 15% water	1285	1.0 to 2.5	0.047 to 0.093
Light sand, 5% water	1285	0.9 to 1.9	0.055 to 0.12

Rocks			
Granite	2650	2.3 to 3.7	0.084 to 0.13
Limestone	2400-2800	2.4 to 3.8	0.084 to 0.13
Sandstone	//	2.1 to 3.5	0.65 to 0.1 1
Wet shale	2570- 2730	1.4 to 2.4	0.065 to 0.084
Dry shale	//	1.0 to 2.1	0.055 to 0.07

Table.III.3: Thermal properties of selected soils, and rocks (ASHRAE, 2011) **[4]**.

III.3.4. Surface type albedo value:

The soil absorbs a large part of the solar energy that reaches it directly (soil not covered by vegetation, floor of aisles between rows of plants, etc.) or transmitted by the vegetation cover. However, even at the scale of one day, this absorption is no longer homogeneous because the spatial distribution the level of the soil surface is very heterogeneous. In addition, the geometry of the greenhouse, and in particular the presence of openings and shadows carried by the structures, can accentuate heterogeneity (Wang and Boulard, 2000). The fraction of the total radiation absorbed by the soil itself depends on the albedo (α; coefficient of reflection of the soil surface). **(Table.III.4)** shows the albedo for different types of soil surface in the short-wave spectral range. The sum of the two fractions, absorbed and reflected by the soil is equal to **1**. The energy absorbed by the soil is restored to sensitive and/or latent heat (convection/ evaporation), either it is stored in deep layers by conduction **[5]**.

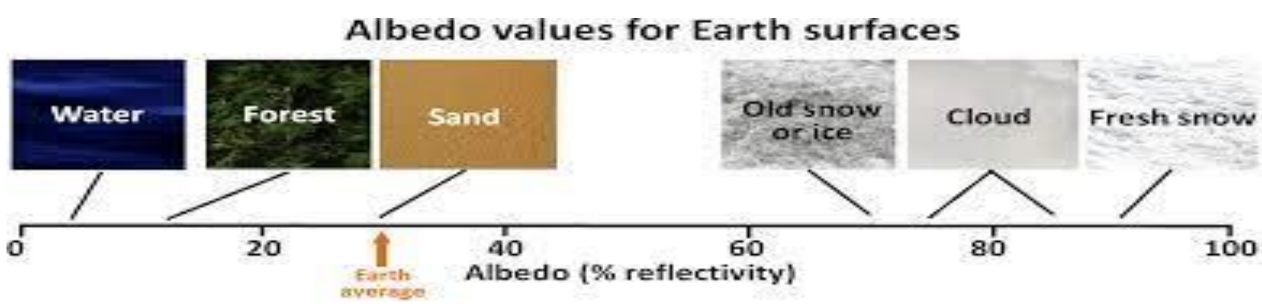


Fig.III.7: Typical albedo values for Earth surface.

Surface type	Value of albedo
Bare Dry Sand	0.35 – 0.45
Wet sand	0.20 – 0.30
Dry clay soil	0.20 – 0.35
Wet bare clay soil	0.10 – 0.20
Wet soil with culms	0.05 – 0.07
concrete surface	0.17 – 0.27

Table.III.4: Albedo values for different soil types **[5]**.

III.4.The mathematical modeling:

III.4.1. Introduction:

The ground temperature at shallow depths is predominantly a function of the upper surface processes that is, climatic conditions such as solar radiation and ambient air temperature. At greater depths, temperature increases with depth according to the geothermal gradient that is determined by the vertical heat flow in the Earth and the thermal properties of local geology. The ground located in closest proximity to the surface is subject to the greatest changes due to climatic variations and atmospheric conditions. Depending on the local climate and ground conditions, the annual temperature variations can typically occur within only the upper 10 m of ground depth. Beyond this depth, there are limited ground temperature variations within the shallow geothermal region **[6]**.

A more accurate method for calculating soil temperature is a numerical soil analysis. The physical domain is then transformed into a network of meshes in which conservation equations are applied. Are generally considered as incoming energy in the domain: solar radiation and convection with air. For outgoing energy: radiation is emitted by the soil and the latent heat of evaporation. Depending on the precision sought, other effects can be taken into account: frost, snow cover, etc.

III.4.2.Heat Balance on the Ground Surface:

On the surface of the ground are the following, presented in **(Fig.III.8)**, heat fluxes: conductive, convective and thermal radiation fluxes. Moreover, on the surface of the ground there is moisture evaporation accompanied by the phase change heat transfer. The heat balance on the surface of the ground has the form as the boundary condition for the ground surface.

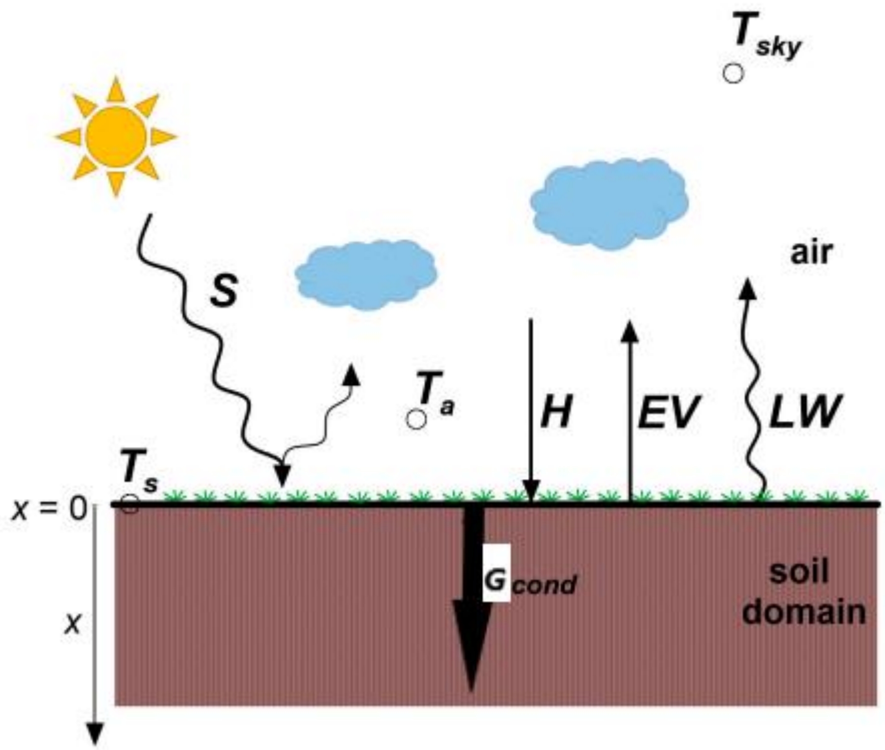


Fig.III.8: Heat fluxes on the surface of the ground **[7]**.

The surface boundary condition presented here considers the heat and moisture flow at the soil atmospheric interface. The energy balance equation is used to provide a description of the annual and diurnal ground temperature variations (Deardorff, 1978). Four major mechanisms of heat exchange between the ground surface and atmosphere are considered, given as (van Wijk, 1966):

- Shortwave heat radiation
- long-wave heat radiation
- Sensible heat
- Latent heat **[6]**.

III.4.2. (a). Heat conduction in the ground:

Heat transfer in the ground occurs mainly as a result of heat conduction. Heat conduction equation is given by:

$$\frac{\partial^2 T}{\partial z^2} = \frac{1}{\alpha} \cdot \frac{\partial T}{\partial t} \quad \text{(III.11)}$$

Where:

T: temperature of the ground **(◦C)**,

α : Thermal diffusivity of the ground **(m²/s)**,

z: Position coordinate **(m)**, and

t: Time **(s)**.

Heat transfer between the ground surface and core soil is only supposed to occur by conduction, in the model. Temperature in the soil is driven by energy flows on the ground, in numerical calculations; the ground is treated as a plate with a finite thickness. On the upper surface of the plate (the ground surface) periodically variable heat fluxes occur. These fluxes are variable both in the annual and daily cycles. Changes resulting from daily cycles occur at depths of less than 1 m. so deep heat flow in the soil is defined by the energy balance equation in general and simplified:

$$G_{cond} = SW^{absorbed} - (LW^{net} + H + EV) \qquad \textbf{(III.12)}$$

Where (G_{cond}) is the total radiation heat flux absorbed or emitted at the soil surface. ($SW^{absorbed}$) is the adsorbed shortwave radiation flux, (LW^{net}) is the net long-wave radiation flux, (H) represents the sensible heat flux and (EV) is the latent heat flux. It is noted that the unit of heat flux used is watts per square metre.

III.4.2.b. Shortwave radiation:

Shortwave radiation is a combination of direct and diffused solar radiation striking the Earth's surface. The diffuse radiation is primarily caused by clouds, dust and molecules scattering in the atmosphere (van Wijk and Scholte Ubing, 1966). This is commonly referred to as shortwave radiation, as the majority of the associated radiation has wavelengths within the infrared and visible bands of the electromagnetic spectrum (van Wijk and Scholte Ubing, 1966). The total shortwave flux striking the Earth's surface varies on a diurnal and annual basis, depending on the solar inclination and climatic conditions. A considerable fraction of the shortwave flux that reaches the Earth's surface is reflected. The exact proportion of the radiation reflected depends on the ground surface coverage and reflection properties. The fraction of the shortwave radiation flux absorbed at the surface can be presented as (Deardorff, 1978).

$$SW^{absorbed} = (1- al) \cdot SW \qquad \textbf{(III.13)}$$

Where **(** $SW^{absorbed}$ **)** is the heat flux associated with the absorbed shortwave radiation and **(al)** is the albedo surface associated with the ground surface type.

III.4.2.c. Net long-wave radiation:

The net long-wave radiation at the ground surface can be described as a combination of long-wave radiation being emitted from the ground and long-wave radiation being absorbed from the atmosphere. Within the context of this formulation, the absorbed radiation is referred to as the long-wave radiation passing from the atmosphere towards the Earth's surface, with the emitted radiation travelling in the opposite direction. This can be expressed as:

$$LW^{net} = SW^{absorbed} - LW^{emitted} \quad \textbf{(III.14)}$$

Where **(**$SW^{absorbed}$**)** is the radiation flux absorbed at the ground surface and **(**$LW^{emitted}$**)** is the radiation flux emitted from the ground surface.

The amount of long-wave radiation absorbed from the atmosphere is dependent on cloud formation. The proposed approaches commonly incorporate coefficients which are specific to local regions. A general approach was formulated by Imberger and Patterson (1981) to calculate the long-wave radiation being absorbed at the ground surface from the atmosphere, given as:

$$SW^{absorbed} = \varepsilon_{lw}^{A}\sigma T_{air}^{4}(1 + 0.17C_{cloud}^{2}) \quad \textbf{(III.15)}$$

Where **(** ε_{lw}^{A} **)** is the long-wave emissivity of the air at ground level (non-dimensional), **(** C_{cloud}**)** is the fractional cloud cover coefficient (C_{cloud}= **0** for clear sky and C_{cloud}=**1** for totally overcast) and **(** T_{air}**)** is the absolute temperature of the air adjacent to the ground surface.

The long-wave radiation being emitted by a body can be calculated using Stefan–Boltzmann's law (Woodward et al., 2001). The Stefan–Boltzmann law states that the energy emitted by a body is directly proportional to the fourth power of its absolute temperature, in this case given as:

$$LW^{emitted} = \varepsilon_{lw}^{s}\sigma T_{s}^{4} \quad \textbf{(III.16)}$$

Where **(**ε_{lw}^{s} **)** is the long-wave emissivity of the body (dimensionless) and s is the Stefan–Boltzmann constant **(** σ**=5.67 W/m²·K⁴)**. T represents the absolute temperature **[6]**.

III.4.2.d. Sensible heat radiation:

Sensible heat radiation can be defined as heat exchange that has an effect on temperature change on constituent objects and is not associated with phase change. Sensible heat radiation is the function of thermal conductivity and convection can be calculated from the following expression **(Kreith and Bohn, 1993) [8]:**

$$H = h_{conv}(T_s - T_{air}) \qquad \textbf{(III.17)}$$

Where **(T_s)** is the soil temperature, **(T_{air})** the ambient temperature above the ground surface and h is the convective heat transfer coefficient at the soil surface and it can be calculated from the equations:

$$h_{conv}=0.5+1.2\sqrt{V_{wind}} \qquad \textbf{[9]} \qquad \textbf{(III.18)}$$

$$h_{conv}=2.8+3\cdot V_{wind} \textbf{ (Duffie and Beckman, 1991) , [8]} \qquad \textbf{(III.19)}$$

And In calculating the heat exchanged between air and ground surface, **(Xamán, J et al)** et relied on the following the equation :

$$H = h_{sur}(T_{air}) \qquad \textbf{(III.20)}$$

(T_{air}) Is the air temperature above the ground surface and **(h_{sur})** is the convective heat transfer coefficient at the soil surface:

$$(h_{sur}) = 5.678\left[0.775 + 0.350\left(\frac{V_{wind}}{0.304}\right)\right] \quad \text{If} \quad (V_{wind}) < 4.880 \qquad \textbf{(III.21)}$$

$$(h_{sur}) = 5.678\left[0.775 + 0.350\left(\frac{V_{wind}}{0.304}\right)^{0.780}\right] \quad \text{If} \quad (V_{wind}) \geq 4.880 \qquad \textbf{(III.22)}$$

- We will use in this study the first relationship **(III.18)**.

III.4.2.e. Latent heat radiation:

Latent thermal radiation can be defined as absorbed or liberated energy while changing a state unchanged in temperature. In this case, this is mainly associated with water evaporation from the upper areas of the ground surface.

$$EV = L_v\cdot E = L_v\cdot\frac{K_{mt}\cdot M_w}{R\cdot T_{air}}(P_{sv}(T_s) - P_v(T_a)) \qquad \textbf{(III.23)}$$

Where

L_v **:** is the latent heat of vaporisation **(J/kg)**,

E **:** is evaporation flux **(kg/s.m²)**,

K_{mt}**:** Mass transfer coefficient **(m/s)**,

M_w**:** Molar mass of water vapour **(kg/mol)**,

R**:** Perfect gas constant **(J/mol.K)**,

P_{sv}**:** Saturating vapour pressure given by:

$$P_{sv}(T_S) = exp\left(25.5058 - \left(\frac{5204.9}{T_S}\right)\right) \quad \textbf{(III.24)}$$

P_v**:** Partial vapour pressure given by:

$$P_v(T_a) = RH \cdot P_{sv}(T_a) \quad \textbf{(III.25)}$$

Where RH: is the Relative humidity.

- And now we can write the final equation of the heat conduction in the ground as follows :

$$G_{cond} = (1-al) \cdot SW - (\varepsilon_{lw}^{s}\sigma T_s^4 - \varepsilon_{lw}^{A}\sigma T_{air}^4(1 + 0.17C_{cloud}^2)) + h_{conv}(T_{air} - T_s) - L_v \cdot E \quad \textbf{(III.26)}$$

III.5. Modeling earth-to-air heat exchangers using analytical method:

III.5.1. introduction:

An analytical specific model is implemented by estimating the thermal behaviour of the (**EAHE)** system. The model was based on a systematic analytical pivotal process developed and expressed using regression analysis. It is used to detect the extent to which some parameters affect the thermal performance of the system, including: (a) the length of the tube; (b) pipe radius; (c) air velocity inside the tube; (d) the depth of the burial underground... etc.

III.5.2. Soil Temperature:

III.5.2.a. Numerical method:

Another potentially more accurate method of calculating soil temperature is through a digital soil analysis. The physical domain is then transformed into a finite discrete mesh network for which the conservation equations are applied. Solar radiation and convection with air are generally considered as input energy in the calculation domain. Outputs of energy are then radiation emitted from the soil and latent heat of evaporation. Depending on the required precision, other effects can be considered such as frost, snow cover, etc. Numerical methods are demanding in terms computing power therefore rarely used to calculate the temperature of undisturbed soil. Their use is justified when complex or unique problems for which detailed information is required **[10]**.

III.5.2.b. Analytical method:

Analytical methods: A first approach consists in finding an equation which makes it possible to easily calculate the temperature. One possibility is to consider the ground as a semi-infinite solid in which only the heat transfer by conduction and according to the Fourier law is considered. These approximations make it possible to calculate a temperature gradient for the soil as a function of the depth. For a given depth, the variation is sinusoidal and depends only on annual variations in the temperature at the surface (Kusuda & Achenbach, 1965). We can represent these variations with equation (1.1) taken from (Carslaw & Jaeger, 1959**) [10]**.

Predictions of soil temperature exhibit a sinusoidal pattern due to the annual fluctuations. Heat conduction in the soil is governed by the following differential equation:

$$\frac{\partial^2 T}{\partial z^2} - \frac{1}{\alpha}\frac{\partial T}{\partial t} = 0 \qquad \text{(III.27)}$$

Where $\alpha_{soil} = \frac{\lambda_{soil}}{\rho C_{soil}}$ is the soil thermal diffusivity.

The corresponding boundary conditions at **(z = 0)** were the following:

$$T(0,t) = T_{surface} = T_{mean} + T_{Amp} \cdot \cos[\omega(t - t_0)] \qquad \text{(III.28)}$$

And for the infinite depth **(z→∞),** $T(\infty, t) = T_{mean}$

An analytical solution of **Eq. (III.26)** is proposed in Carslaw and Jaeger (1959). According to this analytical solution, the temperature at any depth **z** and time **t** can be found by the following expression:

$$T(z,t) = T_{mean} + T_{Amp} \cdot \cos[\omega(t - t_0) - \frac{z}{d}] \cdot \exp(-\frac{z}{d}) \qquad \text{(III.29)}$$

Where $\left(d = \sqrt{\frac{2 \cdot \alpha}{\omega}}\right)$, ω is the frequency of the annual temperature wave,(T_{mean}) is the mean annual ground temperature, which can be approximated from well water at a specific location,(T_{Amp}) is the temperature wave amplitude at the ground surface **(z=0)**. And (t_0) is a phase constant expressed in hours which is defined as the time of occurrence of maximum surface temperature since the start of year **[11]**.

α	T_{mean}	T_{Amp}	t_0	ω	t
2.24×10^{-3}	23	11.75	5112	7.17×10^{-4}	0 ~ 8760
m²/h	°C	°C	h	rd/h	h

Table.III.5: Input parameters.

III.5.3. Inlet air temperature [12]:

The outside ambient temperature prediction model during a year is developed by **Chabane et al. (2016)**. It is based essentially on the minimum temperature data (T_{min}) and the maximum temperature data(T_{max}) , where these parameters are generally based on experimental surveys carried out over several years by meteorological stations in certain geographical site.

Ambient air temperature is giving by this equation:

$$T_{air_{amb}}(t) = T_2 + T_1 \cdot \cos[\frac{(14-t)\pi}{12}] \qquad \textbf{(III.30)}$$

With T_1 :is amplitude of soil surface temperature variation calculated as follows (°**C**):

$$T_1 = \frac{T_{max} - T_{min}}{2} \qquad \textbf{(III.31)}$$

T_2 : is the mean annual temperature calculated as follows (°**C**):

$$T_2 = \frac{T_{max} + T_{min}}{2} \qquad \textbf{(III.32)}$$

III.5.4. Mathematical modeling of EAHE:

The airflow into the buried pipes transmitted energy into the soil that has effect on soil temperature over a year. In the present model, the undisturbed soil temperature is at a specified finite radius. And, air pressure and velocity are assumed to be constant over the length of the pipe.

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 travelled by the fluid, which is described by the following steady analytical model (Mehdid et al., 2018) **[12]**.

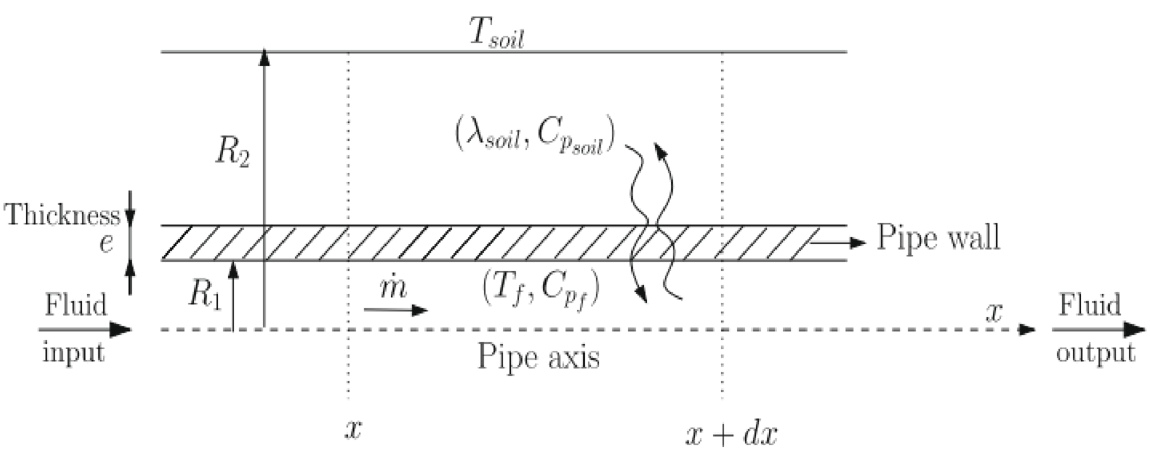


Fig.III.9. Schematic heat exchange between flowing fluid and ground. **[10]**

$$\boldsymbol{T_{out}(L) = T_{soil} + (T_{in} - T_{soil}) \cdot \exp\left(\frac{-U}{\dot{m}Cp_{air}} L\right)} \qquad \textbf{(III.33)}$$

With

$\boldsymbol{L}$**:** The pipe length,

$\boldsymbol{T_{in}}$: Corresponds to the outside ambient temperature **(ºC)**,

$\dot{m}$: Mass flow of air in the pipe **(kg /s)**,

Cp_{air}: Specific heat at constant pressure of the air **(J/kg·K)**, and

U: Overall heat transfer coefficient between air and soil **(W/m²·K)**, calculated accordingly to the next relation:

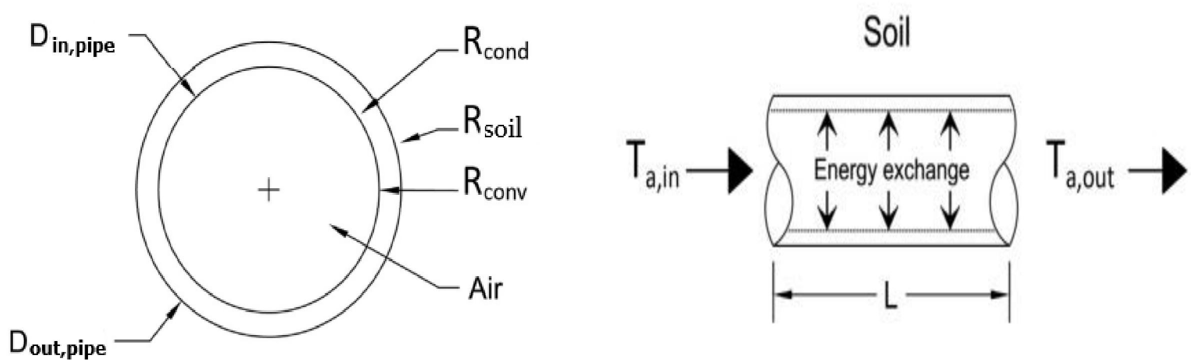


Fig.III.10. Schematic diagram of the modeled EAHE system **[13]**.

$$U = \frac{1}{R_{tot}} \quad \textbf{(III.34)}$$

Where R_{tot} is the total thermal resistance of the system, which can be obtained from Eqs:

$$R_{tot} = R_{conv} + R_{cond} + R_{soil} \quad \textbf{(III.35)}$$

R_{conv} : Thermal resistance convection between air and tube **(m^2.K/W)** is expressed by the equation next:

$$R_{conv} = \frac{1}{\pi \cdot D_{in,pipe} \cdot h_c} \quad \textbf{(III.36)}$$

R_{cond}**:** Thermal resistance of buried tube (m.K/W) calculate with the next expression:

$$R_{cond} = \frac{1}{2\pi\lambda_{pipe}} ln(\frac{D_{out,pipe}}{D_{in,pipe}}) \quad \textbf{(III.37)}$$

R_{soil}**:** Thermal resistance between tube and ground **(m^2.K/W)**, expressed by:

$$R_{soil} = \frac{1}{2\pi\lambda_{soil}} ln(\frac{D_{out,pipe}+D_{in,pipe}+D_{soil}}{D_{in,pipe}}) \quad \textbf{(III.38)}$$

D_{soil}: Radius of the adiabatic soil layer **(m)**,

λ_{pipe}: Thermal conductivity of the buried pipe **(W/m.K)**,

λ_{soil}: Thermal conductivity of soil **(W/m.K)**,

h_c: Convection coefficient of air **(W/m². K)** is calculated from the Nusselt number, for a turbulent flow within a circular duct cross-section, expressed by:

$$h_c = \frac{Nu \cdot \lambda_{soil}}{D_{in,pipe}} \quad \textbf{(III.39)}$$

Where the number of **Nusselt** is given by the following relation **[12]:**

$$Nu = 0.214 \times (Re^{0.8} - 100) \times Pr^{0.4} \quad \textbf{(III.40)}$$

With, Re: is the **Reynolds** number:

$$Re = \frac{\rho_{air} V_{air} D_{in,pipe}}{\mu_{air}} \quad \textbf{(III.41)}$$

Pr: is the **Prandtl** number:

$$Pr = \frac{\mu_{air} Cp_{air}}{\lambda_{air}} \quad \textbf{(III.42)}$$

With:

V_{air}: Average air velocity in the system pipe **(m/s)**,

$D_{in,pipe}$: Inside diameter of pipe **(m)**,

μ_{air}: Dynamic viscosity of the air **(kg/m.s)**, and

λ_{air}: Thermal conductivity of the air **(W/m. K) [13]**.

Material	Density (kg/m³)	Specific heat capacity (J/kg.K)	Thermal conductivity (W/m.K)
Soil	1800	1340	1.5
Air	1,225	1005	0.0242
PVC	1380	900	0.16

Table.III.6: Physical and thermal parameters used in simulation.

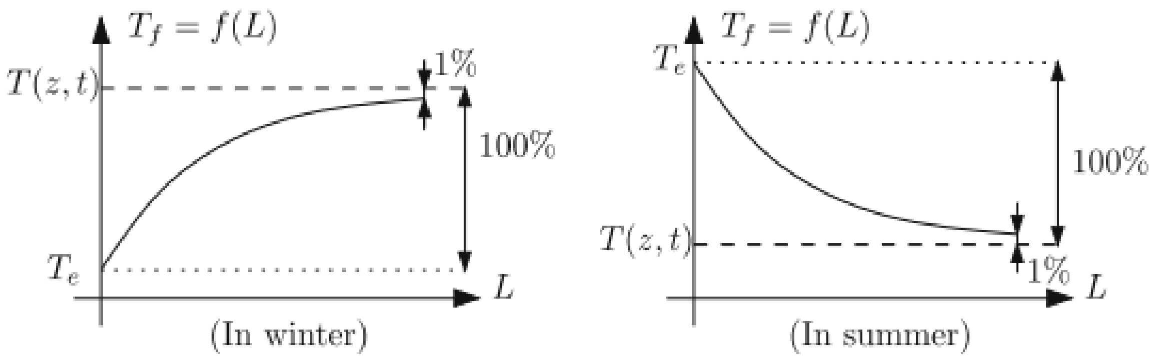


Fig.III.11. Evolution of the temperature air as a function of the length L, in winter and in summer **[11]**.

III.6.Conclusion:

For the simulation of the parameters determining the functioning, a computer program under **MATLAB**, which has two sub-programs, the first is based on the mathematical soil temperature evaluation model, in order to estimate the variation in soil temperature at several depth levels as a function of time. The second program is based on the calculation of the air temperature as a function of the length of the heat exchanger while varying the thermal dimensioning parameters.

Reference:

[1] Incropera, F. P., & DeWitt, D. P. (2018). *Fundamentals of heat and mass transfer*. New York: J. Wiley.

[2] Cengel, Y. A., & Ghajar, A. J. (2014). *Heat and mass transfer: Fundamentals and applications* (5th ed.). McGraw-Hill Professional.

[3] BOUCHANDOUKA R., & LAYEB I. (2019). *Etude du comportement thermique d'un échangeur air/sol (application au site de Biskra)* (Master's thesis).

[4] Gouda, A. (2010). Using of geothermal energy in heating and cooling of agricultural structures. *Benha University*.

[5] Mesmoudi, K. (2010). *Etude Expérimentale et Numérique de la Température et de l'Humidité de l'Air d'un Abri Serre Installé dans les Haut Plateaux d'Algérie, Région des Aurès* (Doctoral dissertation, Université de Batna 2).

[6] Sedighi, M., Hepburn, B. D., Thomas, H. R., & Vardon, P. J. (2016). Energy balance at the soil atmospheric interface. *Environmental Geotechnics*, *5*(3), 146-157.

[7] Larwa, B. (2018). Heat transfer model to predict temperature distribution in the ground. *Energies*, *12*(1), 25.

[8] İŞ, M. Ş., & YILMAZ, T. Adana İçin Toprak Sıcaklığının Hesaplanması. *Çukurova Üniversitesi Mühendislik-Mimarlık Fakültesi Dergisi*, *25*(1), 95-104.

[9] MABROUKI, D. (2014). *Étude de l'influence des paramètres climatiques sur la température du sol (application au site de Biskra)* (Master's thesis).

[10] Patin, M. (2020). *Étude des performances d'un échangeur géothermique air-sol horizontal placé autour des fondations d'un bâtiment résidentiel* (Doctoral dissertation, École de technologie supérieure).

[11] Derbel, H. B. J., & Kanoun, O. (2010). Investigation of the ground thermal potential in tunisia focused towards heating and cooling applications. *Applied thermal engineering*, *30*(10), 1091-1100.

[12] HAMDANE, S. (2021). *Parametric Study of Air/Soil Heat Exchanger Destined for Cooling/Heating the Local in Arid and Semi-Arid Regions* (Doctoral dissertation, Université Mohamed Khider–Biskra).

[13] Fazlikhani, F., Goudarzi, H., & Solgi, E. (2017). Numerical analysis of the efficiency of earth to air heat exchange systems in cold and hot-arid climates. *Energy conversion and management*, *148*, 78-89.

CHAPTER

IV

Numerical resolution, Results and Discussion

IV.1. Numerical resolution:

IV.1.1. Mathematical formulation of this problem:

We impose that the soil is a homogeneous semi-infinite mass whose physical properties are fixed and independent of the depth subject to the conductive flux, the mathematical formulation of this problem is based on the conduction equation, which with the boundary and ground-air interface conditions is solved by the finite volume method **(FVM)**. Depending on the limiting conditions, the equation of the thermal conduction in the soil considered two-dimensional is of the form as follows:

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial z}(\lambda \frac{\partial T}{\partial z})$$

Where:

ρ : Average soil density in **(kg/m^3)**,

C_p: Average mass heat capacity of the soil in **(J/kg K)**,

λ: Average soil thermal conductivity in **(W/m K)**,

T: Temperature in **(K)** at a point on the ground marked by the coordinates **(x, y)**, and at the moment **t** in **(s)**.

(x, z): Spatial coordinates of the point considered in the ground in **(m)**.

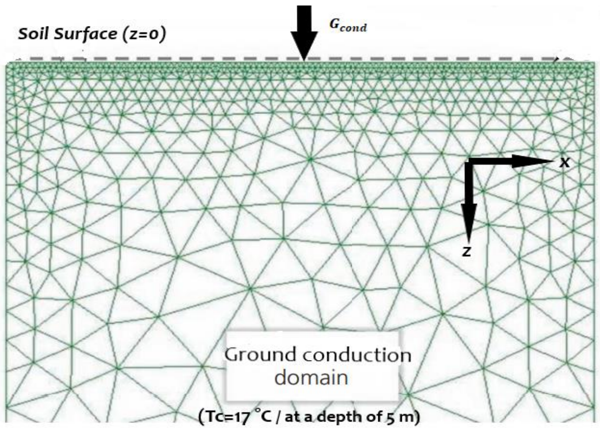


Fig.IV.1.Modelling of conductive transfer in soil.

The proposed numerical method is based on iterative incremental resolution based on the initialization of temperatures in the nodes for a value of 17°C, the temperature value corresponding to the reading of the average ground temperature at a depth of 05 metres.

IV.1.2. Boundary condition and the climatic data:

The finite volume method **(FVM)** in **MATLAB** environment was used for the simulations, to solve the unsteady heat transfer problem in a 2D computational domain. A model of the energy balance at the ground surface has been developed, based on the ground surface properties (albedo and emissivity) and weather variables (solar radiation, air temperature, relative humidity, atmospheric pressure and wind speed) **Fig.IV.2**. For a realistic simulation of the environmental conditions, the weather data for Biskra was used. **Table .IV.1**.

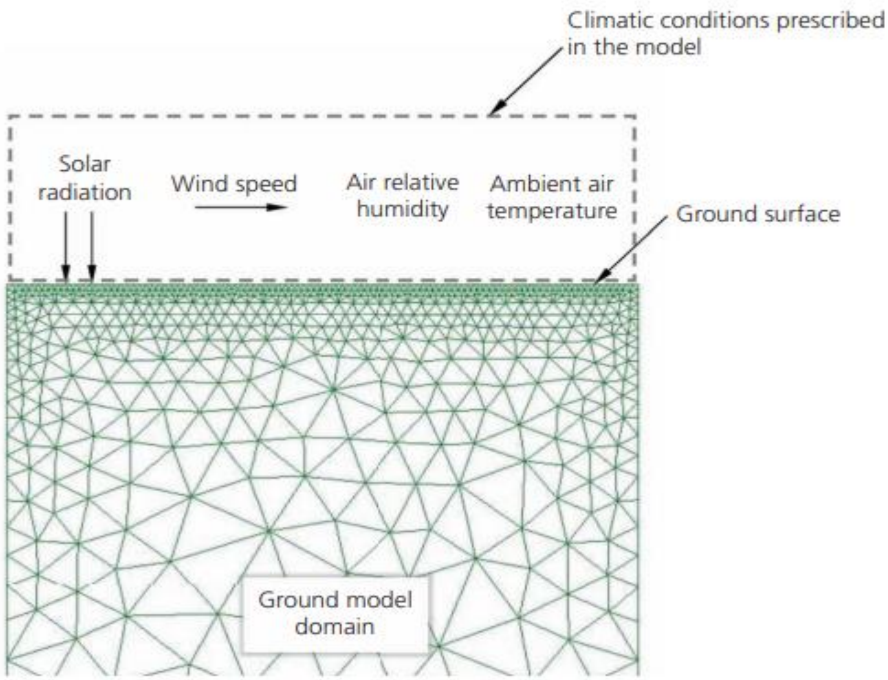


Fig.IV.2: Schematic diagram of a ground domain showing the ground surface boundary condition and the climatic variables required in order to calculate the ground surface boundary components **[1]**.

Biskra (34 ° 51 '00 "N 5 ° 44' 00" E) is a city located in north of the Sahara, in the foothills of the Aures and Zab Mountains, 400 km south-east of Algiers, capital of Algeria.

IV.1.2.a. Biskra climate according to Köppen-Geiger classification:

Biskra Climate is sropical and subtropical desert **[2]** this climate is dominated in all months by the subtropical anticyclon, or subtropical high, with its descending air, elevated inversions, and clear skies. Such an atmospheric environment inhibits precipitation. Most of Earth's tropical, true desert climates occur between 15 and 30 latitude. The most extreme arid areas also are far removed from sources of moisture-bearing winds in the interiors of continents and are best developed on the western sides of continents, where the subtropical anticyclone shows it is most intense development **[3]**.

IV.1.2.b. Meteorology data for the city of Biskra:

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average temperature (°C)	11.9	13.7	16.2	20.0	25.2	29.9	33.5	32.7	27.5	22.1	16.5	12.8
Average relative humidity (°C)	0.57	0.52	0.44	0.40	0.37	0.31	0.29	0.31	0.40	0.49	0.57	0.60
average wind speed (m/s)	3.70	4.18	4.59	4.82	4.78	4.34	3.70	3.82	3.58	3.82	3.60	3.65
Average sunshine (W/m²)	211.7	295.5	411.7	489.7	511.2	533.5	525.1	476	398.8	304.2	219.2	177.7

Table .IV.1: Meteorological Data **[4]**.

IV.1.2.c. Physical properties of the soil in the Biskra region:

- **The soil type of the Biskra region is generally ‘’sandy clay loam’’**

Density (ρ_{soil}),(kg/m³)	Heat capacity (Cp_{soil}),(J/kg.°C)	Thermal conductivity (λ_{soil}),(W/m.°C)	Thermal diffusivity (α_{soil}),(m²/s)	Surface Emissivity (ε_{soil}),(-)	Surface Albedo (al),(-)
1800	1340	1.5	6.22×10^{-7}	0.73	0.35

Table. IV.2: Physical properties of soil.

IV.1.3.Calculation algorithms:

- **Numerical model of Ground temperature:**

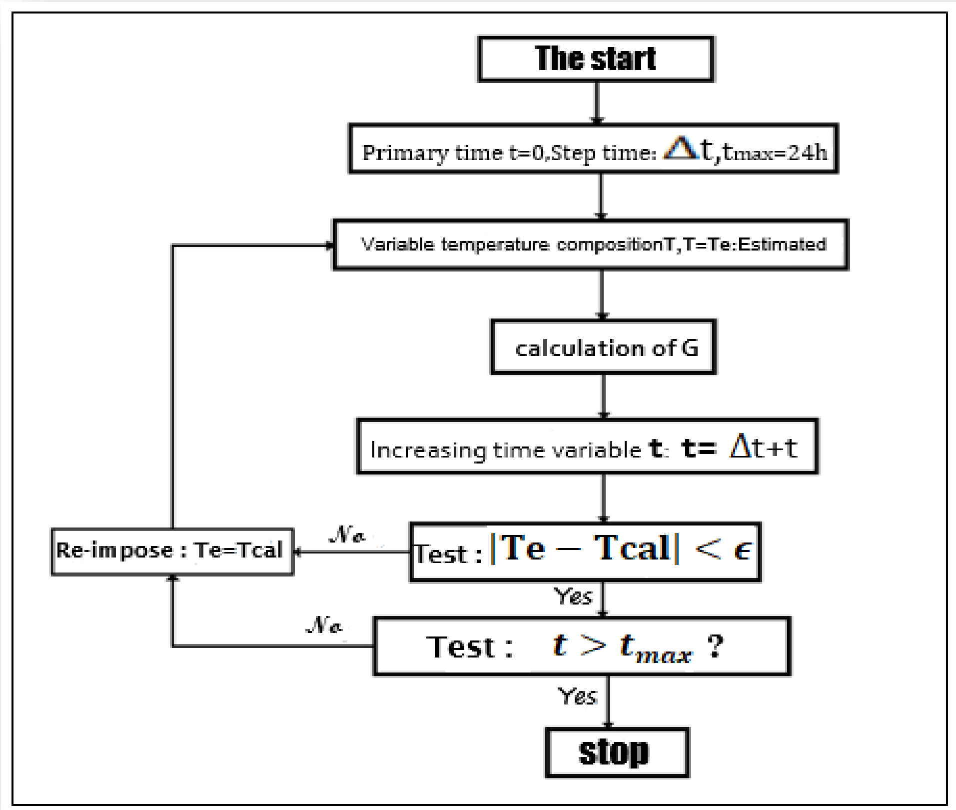


Fig.IV.3: Calculation algorithm within 24 hours.

- **EAHE model :**

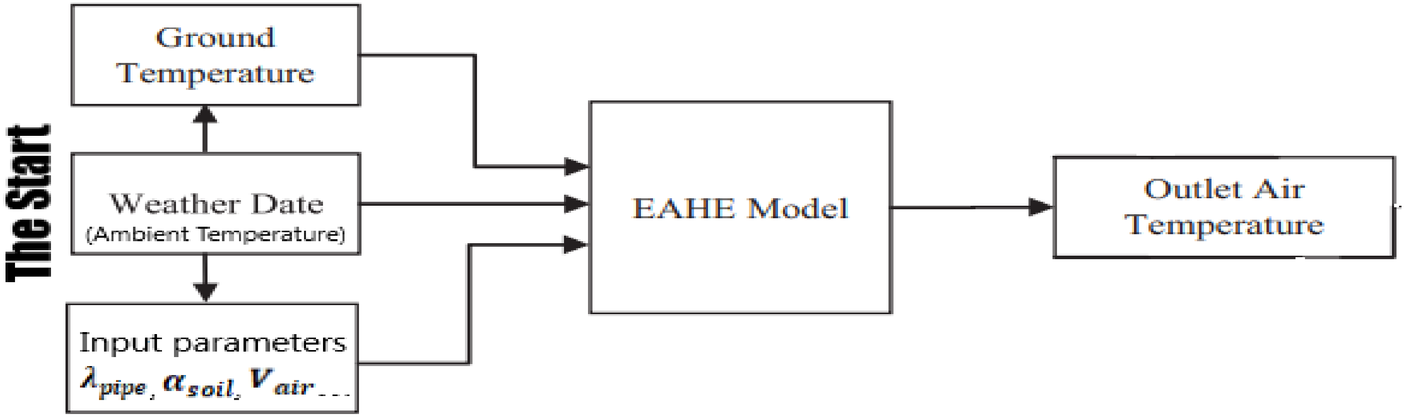


Fig.IV.4: Calculation algorithm of outlet temperature.

IV.2. Results and discussion:

IV.2.1. Influence of environmental parameters on soil temperature:

- The parameters entered are the same as the average values taken from the (**Table .IV.1**), except for air temperature, which is approximated by the outside ambient temperature model (a sinusoidal function).

IV.2.1.a. *Effect of surface albedo:*

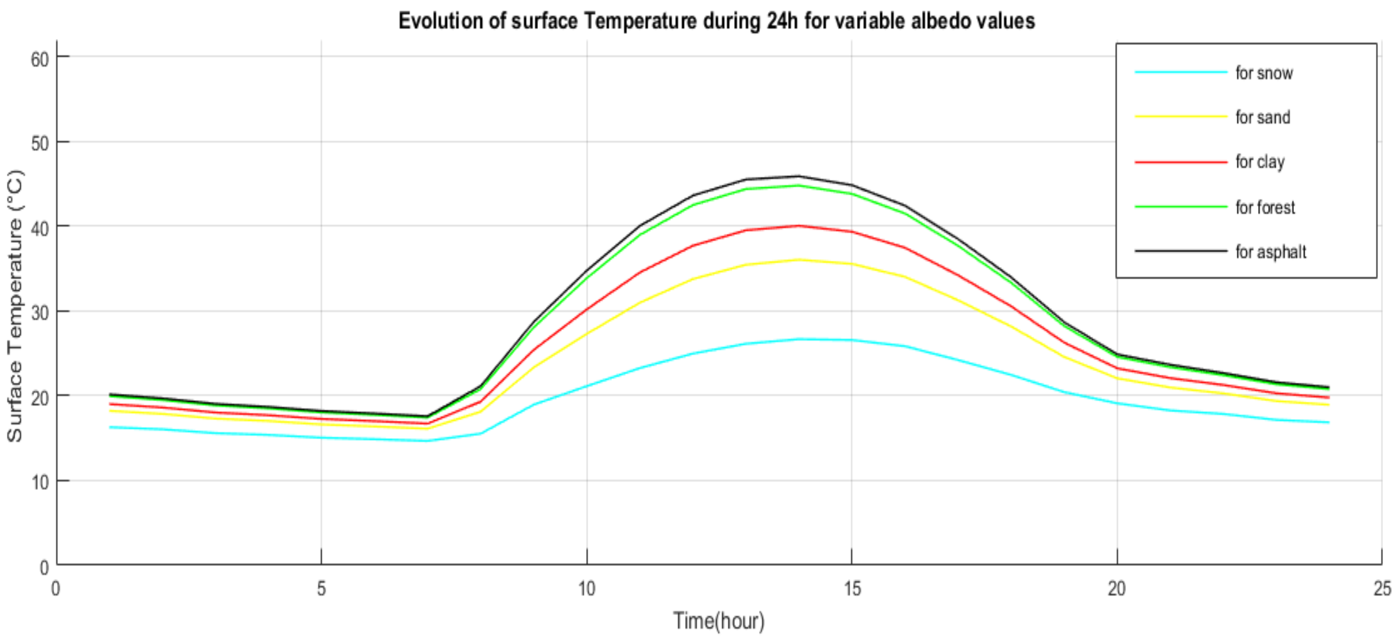


Fig.IV.5: Evolution of surface temperature during 24h for variable albedo values.

- The **(Fig.IV.5)** shows the developments of the ground surface temperature with each change in the value of surface albedo, we note that surfaces that tend to darken like Asphalt have high temperatures, while those that tend to whiten like snow are low, because the shortwave radiation incident from the sun when it falls on white surfaces is mostly reflected and not absorbed by the ground, keeping the ground or body cold.

This observation can be exploited as the researcher did (Shweta Sharma and al **[5]**) where they studied the effect of surface albedo change (using white paint on surfaces in India) on the change in the temperature of the ground surface. The study concluded that use of cool roofs in India could compensate the heating due to increase in CO_2 (from pre-industrial to current times) by ~ 5%.

IV.2.1.b. *Effect of Wind speed:*

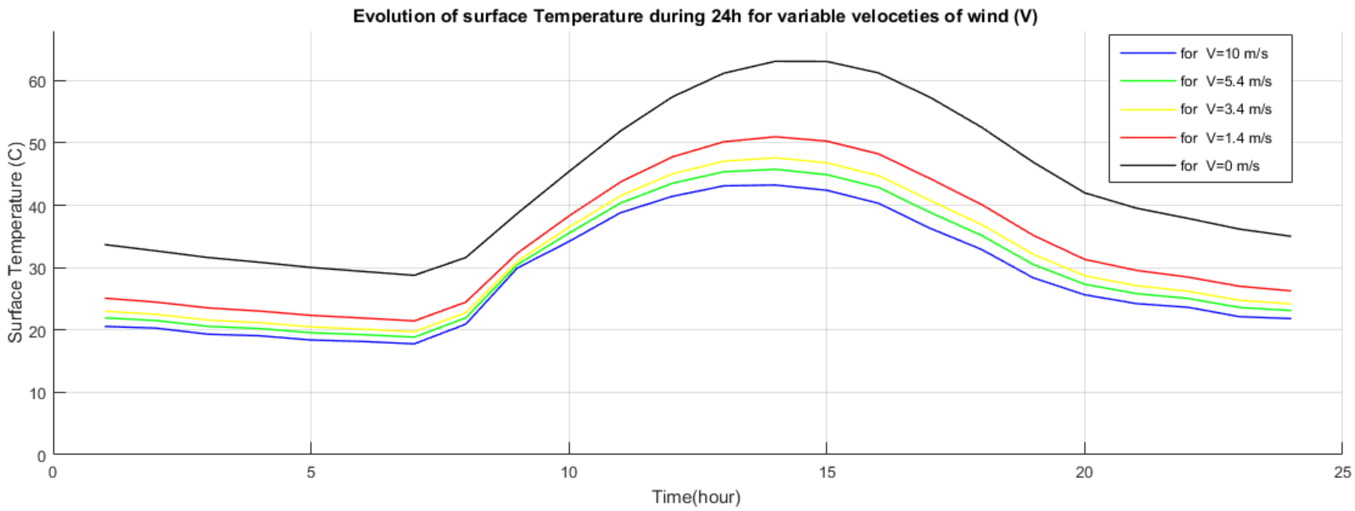


Fig.IV.6: Evolution of surface temperature during 24h for variable wind speed values.

- The (**Fig.IV.6)** shows the developments of the ground surface temperature with each change in the wind speed value, we note that when the wind speed increases the temperature on the ground decreases, because when the wind accelerates, the value of convective heat transfer coefficient increases, This heat exchange between the ground surface and the air so sensible heat flux increases, and the ground cools rapidly.

IV.2.1.c. *Effect of surface emissivity:*

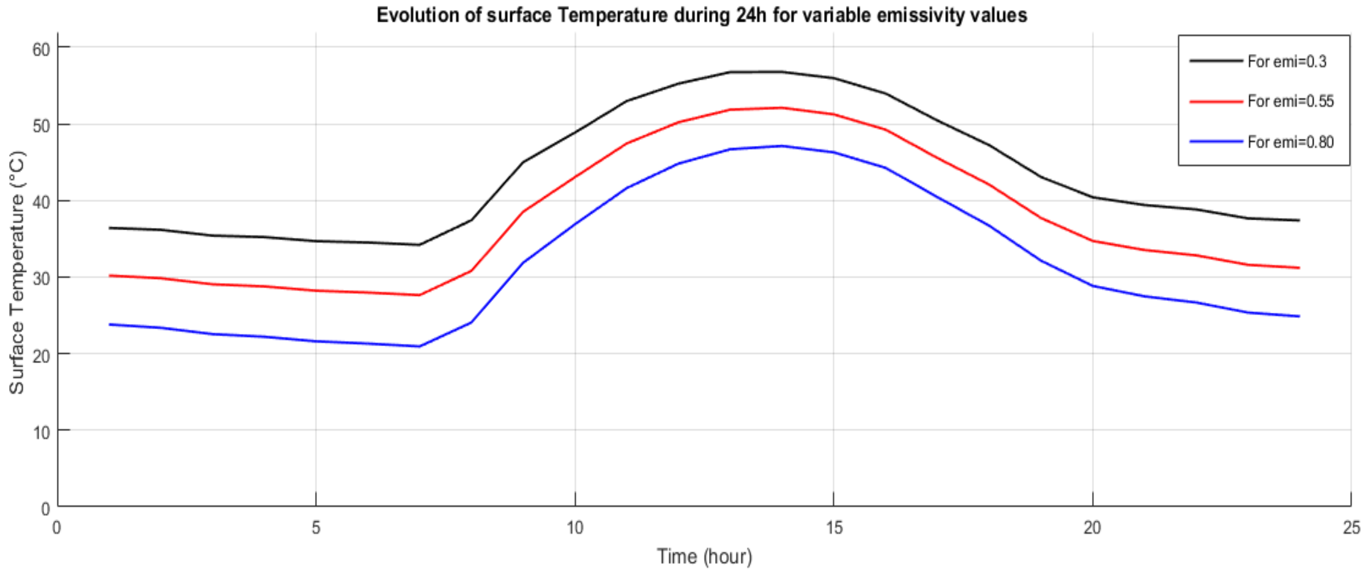


Fig.IV.7: Evolution of surface temperature during 24h for variable emissivity values.

❖ The **(Fig.IV.7)** shows the developments of the ground surface temperature with each change in the value of surface emissivity, and this is because the more the emissivity of the body (ground) increases the amount of radiation it emits, keeping the body (ground) cold.

IV.2.1.d. ***Effect of relative humidity:***

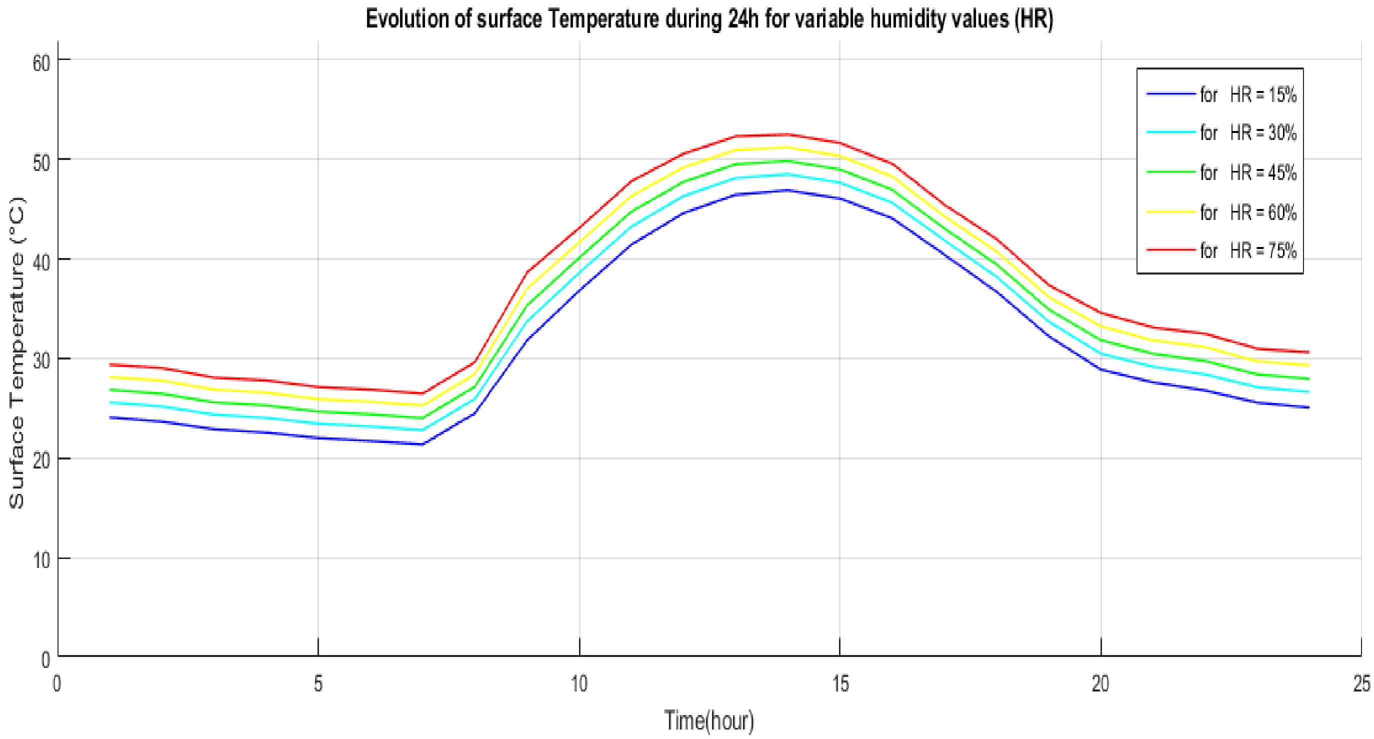


Fig.IV.8: Evolution of surface temperature during 24h for variable relative humidity values.

❖ The **(Fig.IV.8)** shows the developments of the surface temperature of the ground with each change in the value of humidity, we note that when the humidity increases the temperature on the ground decreases, because when the humidity augments, the vapour pressure approaches to the saturation vapour pressure, and Thus, the ground keeps its heat and does not participate in the evaporation process as a latent heat.

IV.2.1.e. *Effect of fractional cloud cover coefficient:*

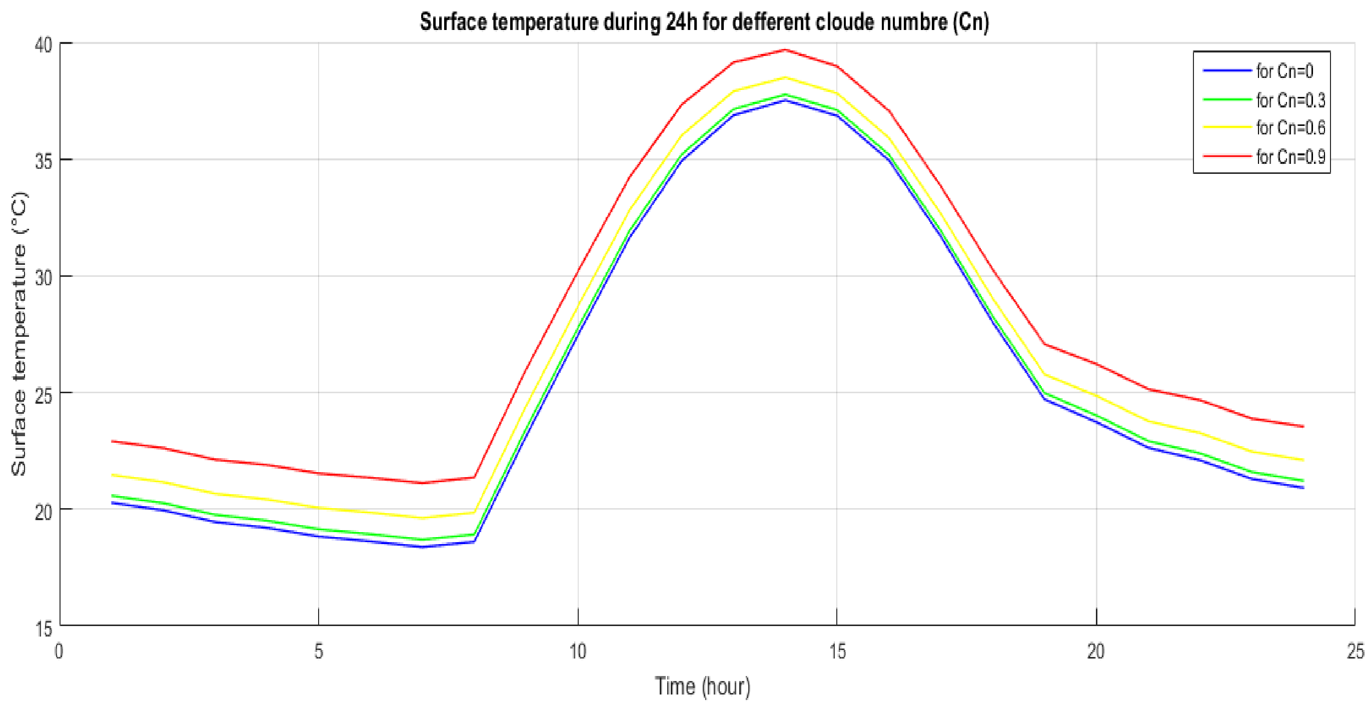


Fig.IV.9: Evolution of surface temperature during 24h for variable cloud number values.

- The **(Fig.IV.9)** shows the developments in the surface temperature of the ground with each change in the value of the cloud cover coefficient. We notice that when the cloud cover coefficient increases, that is, the more clouds the sky is covered, the temperature on the ground increases, because these clouds trap the radiation reflected from the ground, And it reflects back to it again and again, which means that the radiation on the ground is increased.

IV.2.2. Ground temperature and Heat conduction in the ground with numerical model:

- It was based on experimental data provided by :Dr. **Chabane Fouad**

IV.2.2.a. Winter's day:

- **Ground temperature:**

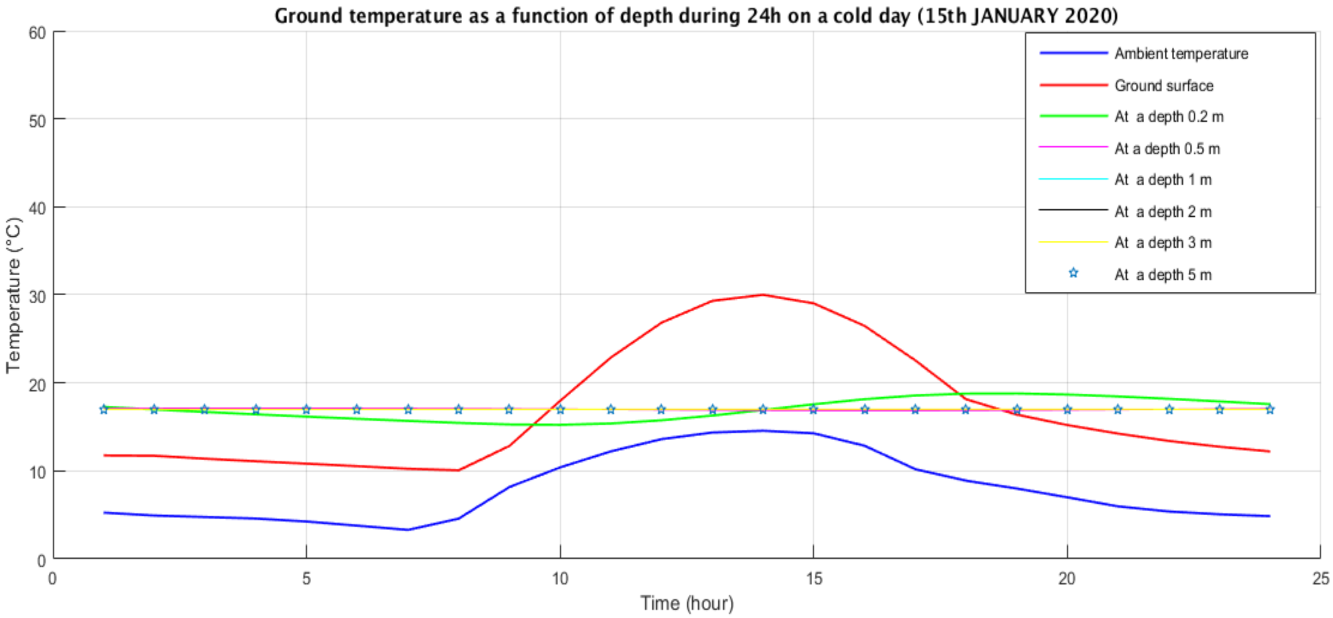


Fig.IV.10: Ground temperature as a function of depth 24h on cold day JANUARY.

- **Heat conduction in the ground and shortwave radiation:**

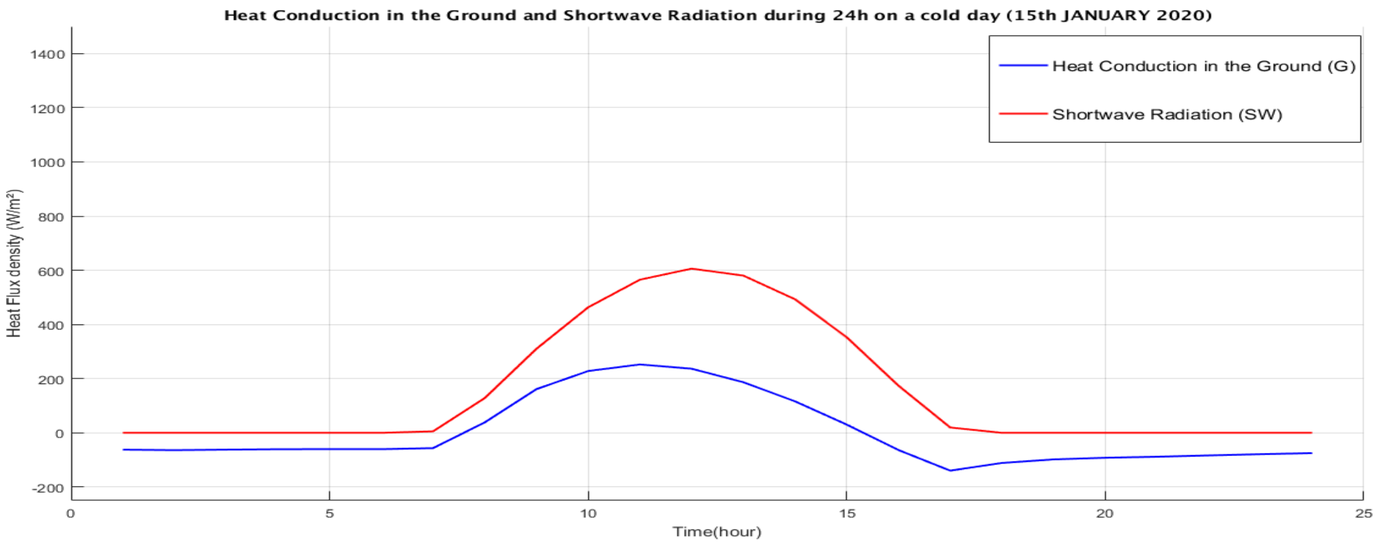


Fig.IV.11: Heat conduction in the ground and shortwave radiation during 24h on cold day JANUARY.

IV.2.2.b. Summer's day:

- **Ground temperature:**

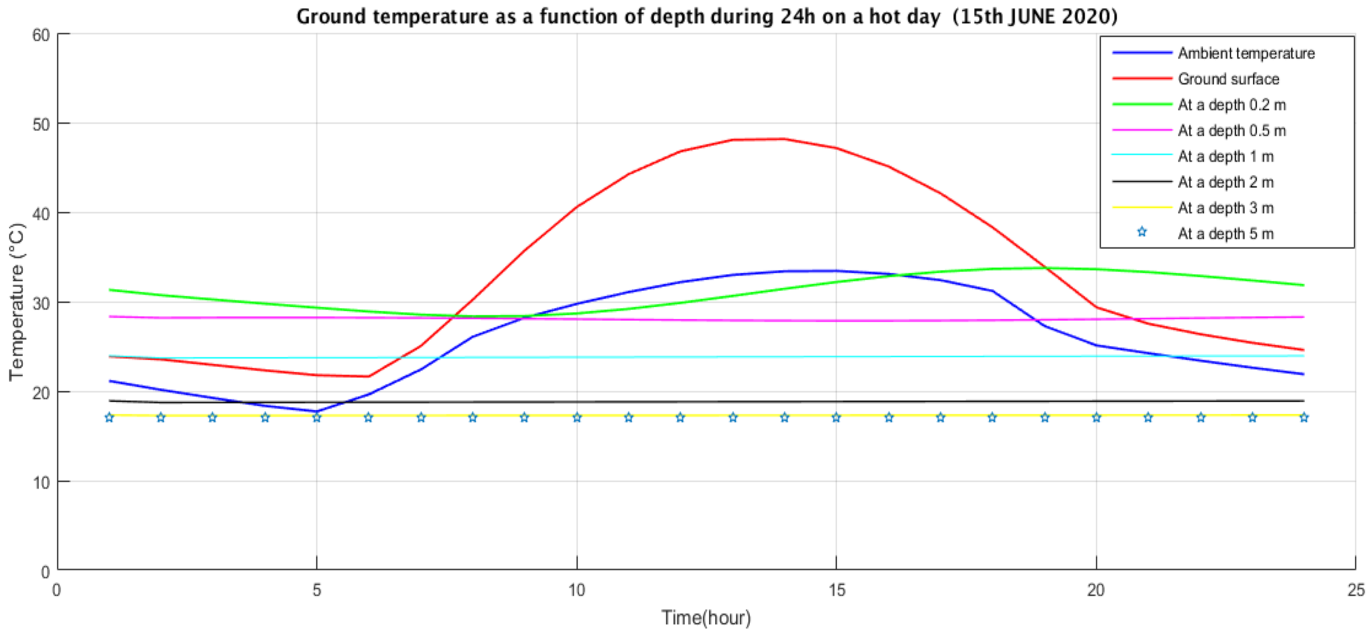


Fig.IV.12: Ground temperature as a function of depth 24h on hot day JUNE.

- **Heat conduction in the ground and shortwave radiation:**

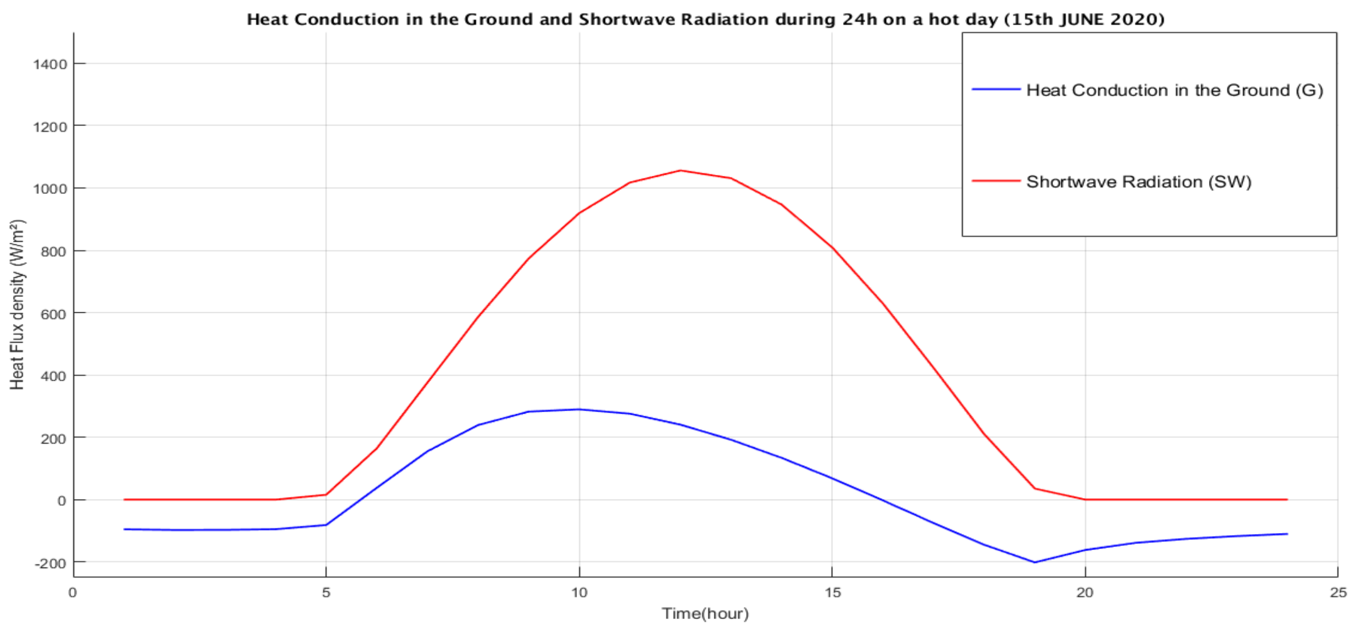


Fig.IV.13: Heat conduction in the ground and shortwave radiation during 24h on hot day JUNE.

- Figures (**Fig.IV.10**) (**Fig.IV.11**) (**Fig.IV.12**) (**Fig.IV.13**) showing the distribution of the ground temperatures by depth, amount of solar radiation and heat conduction in the ground 24 hours in two days of the year (summer's and winter day), we note that the distribution of temperatures begins to gradually decrease from the surface of the earth to a certain depth where the soil temperature is constant and this depth is about 3 meters at a temperature of about (18°C). We note that in winter the ambient air temperature is lower than the soil temperature at this depth. In summer, the temperature of the ambient air is larger than the temperature of the soil.
- The ground can serve as a heatsink to cool a building or an agricultural greenhouse, but also as a source of heat to provide heating during the cold periods of the year.

IV.2.3. Soil temperature with analytical model:

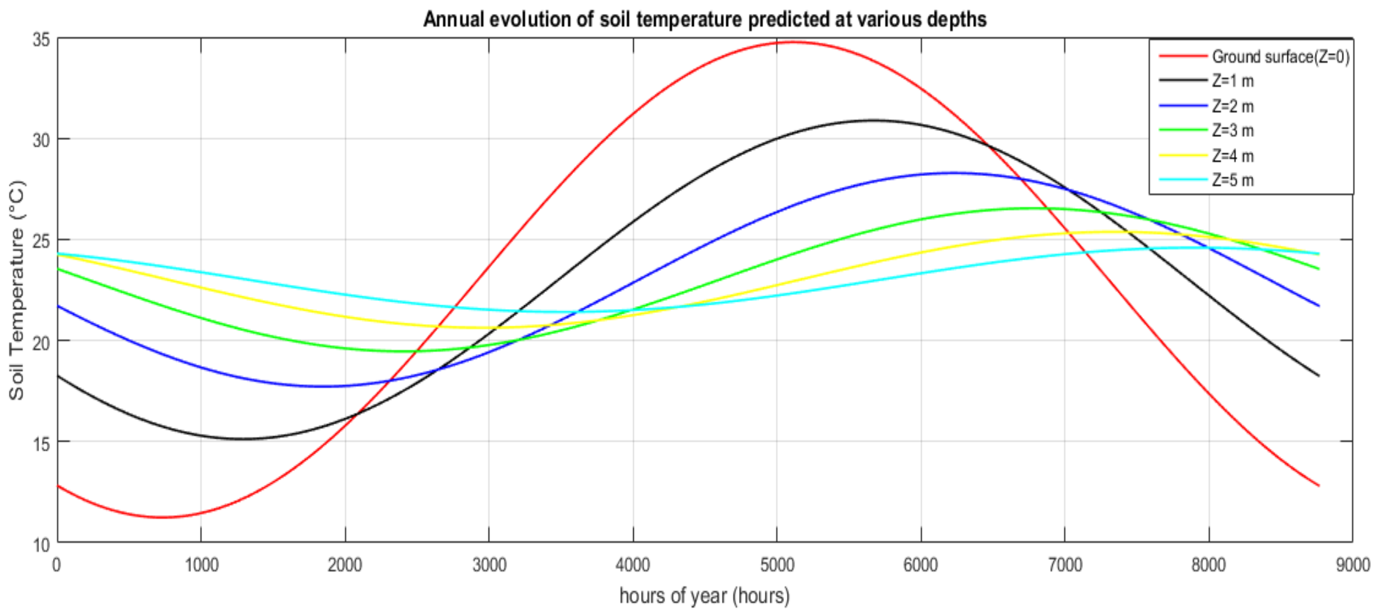


Fig IV.14: Annual evolution of soil temperature predicted at various depths.

- **Fig IV.14**, shows the variation of the soil temperatures during a year at different depths from 0 to 5 meters. , where ;it's noted that at a depth of 5 meters the temperature changes from a minimum degree of 23°C and High temperatures are estimated at 34,75°C in July ,at the ground surface.

IV.2.4. The outside ambient temperature model:

- Inputs **(T_{max}, T_{min})** are based on the following reference: **[6]**.

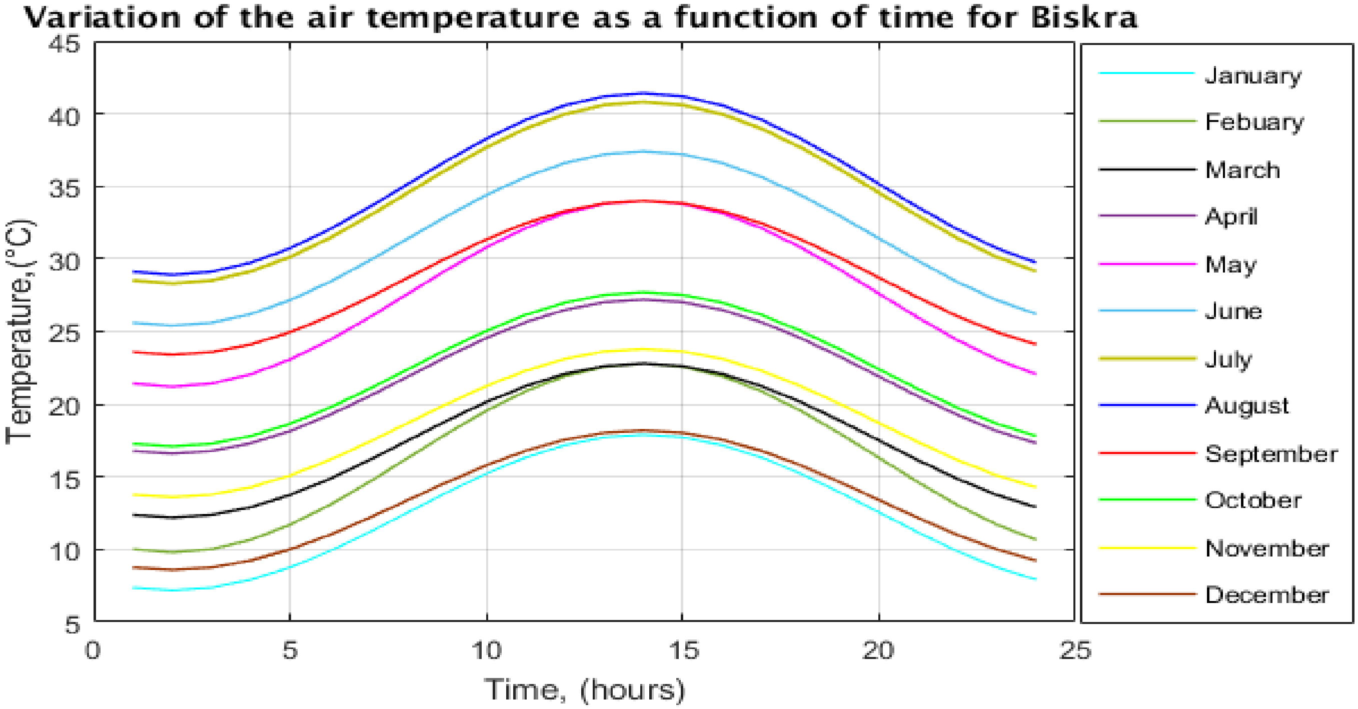


Fig IV.15: Variation of the air temperature as function of time for Biskra.

The **Fig IV.15** Present the simulation by **MATLAB** showed in the form of curves the evolution of the external ambient temperature for the Biskra region.

IV.2.5. Influence of parameters on (EAHE) system:

- **Soil temperature T_{soil}=17°C**

IV.2.5.a. Effect of pipe length:

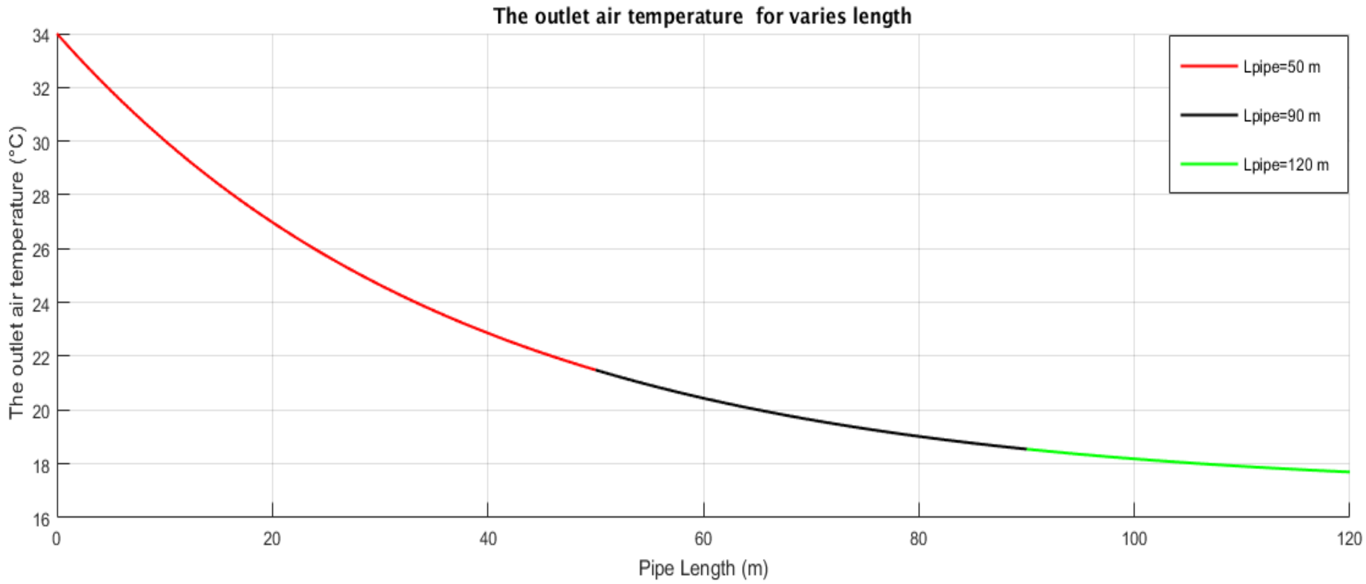


Fig IV.16: The outlet air temperature of velocity =2m/s for varies length of pipe

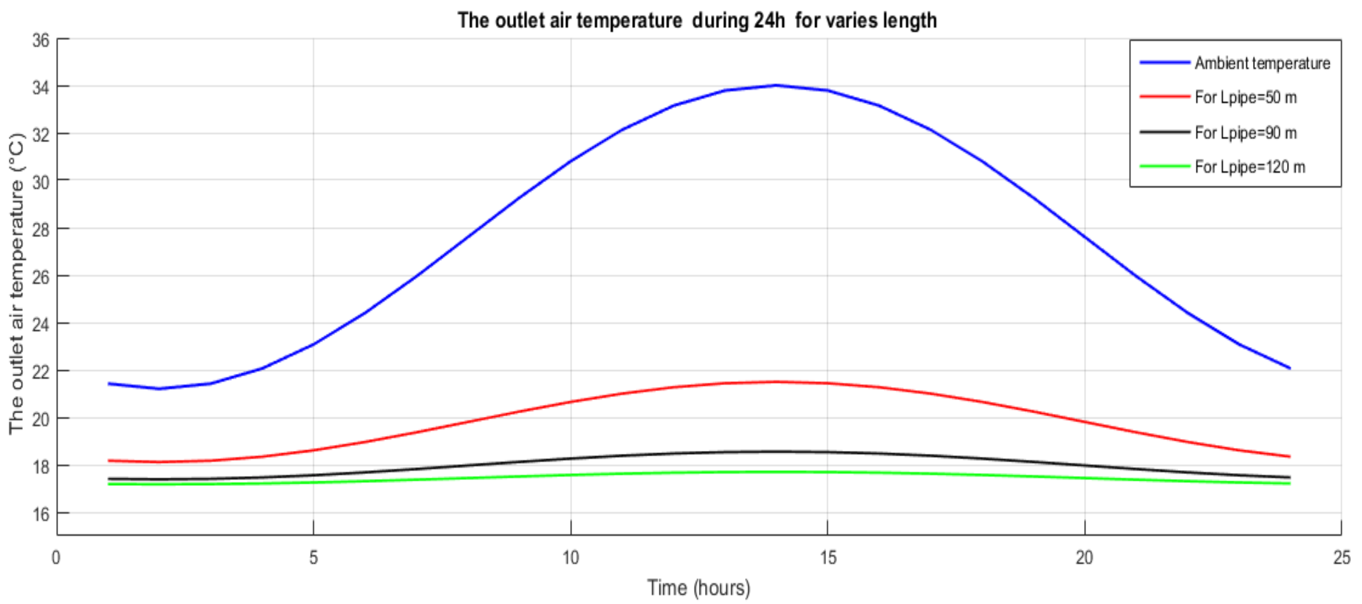


Fig IV.17: Ambient and outlet air temperatures (EAHE) system during 24h for varies length.

❖ From the **Fig IV.16** and **Fig IV.17**, which shows the evolution of the air temperature and efficiency as a function of the length of the underground duct (air/ground), it is evident that the speed of the curves begins to stabilize on 50 m of total exchange length, which corresponds to the optimal length of the buried heat exchanger. However, it can be seen that above 50m to 120m, the temperature difference becomes insignificant in order to reach the soil temperature, on the other hand, any increase in the length in order to achieve better performance is penalized by an additional loss of load and a high cost of achievement compared to the difference in temperature achieved between the air conveyed and the ground.

IV.2.5.b. Effect of airflow velocity:

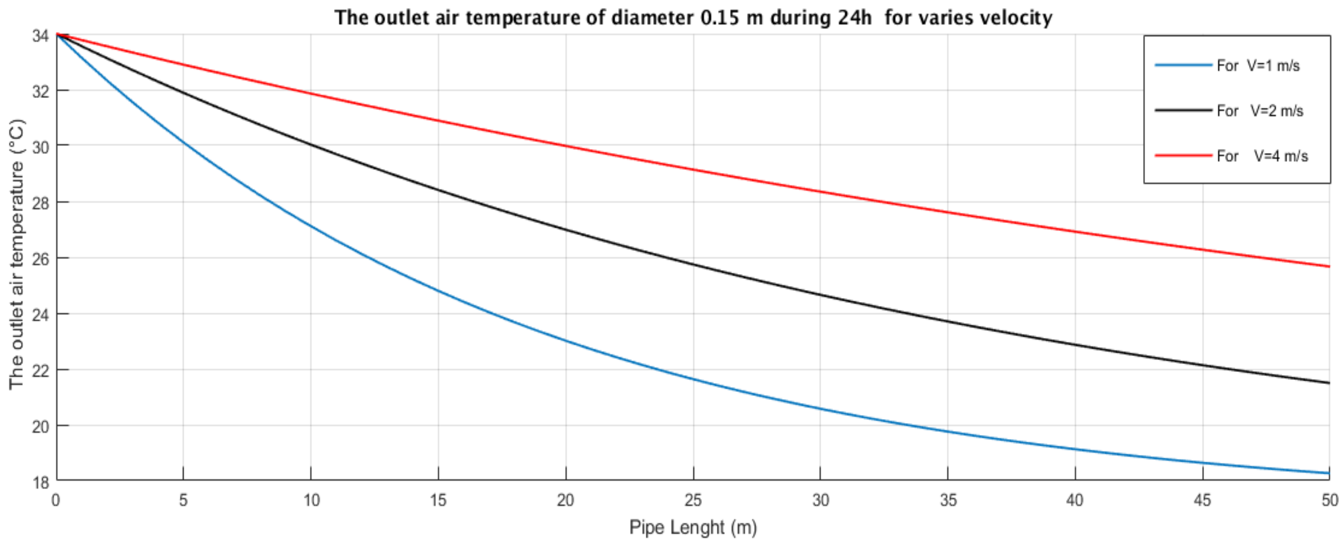


Fig IV.18: The outlet air temperature of diameter =0.15m for varies velocity of air.

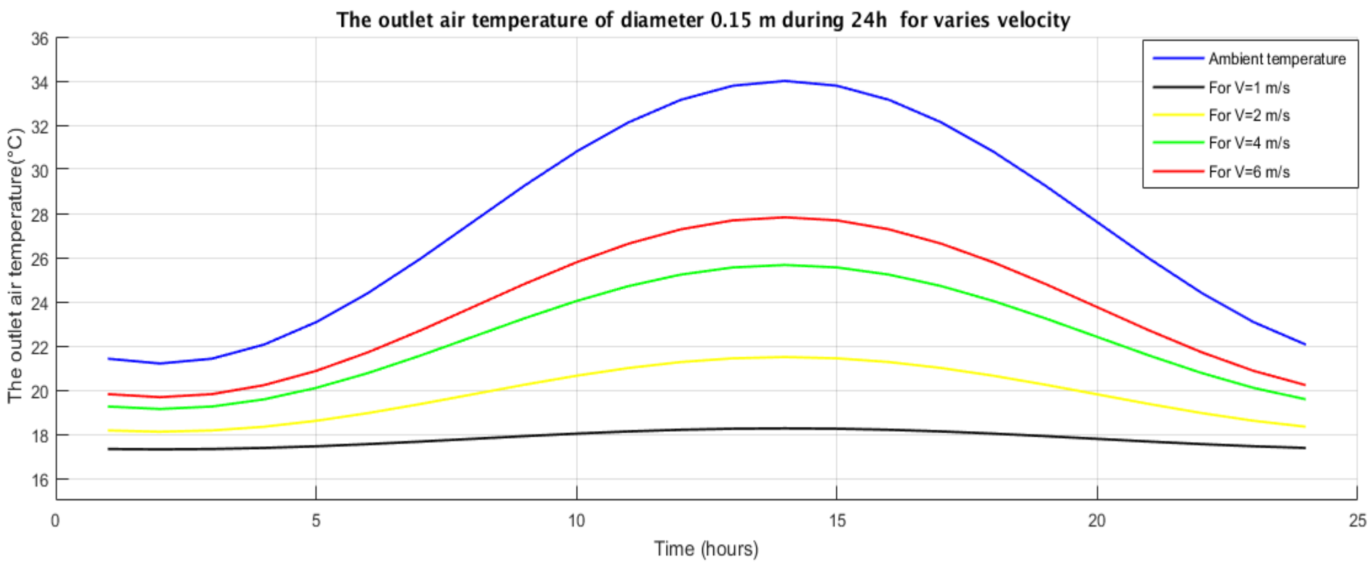


Fig.IV.19: Ambient and outlet air temperatures (EAHE) system during 24h for varies velocity.

❖ Air velocity is a key milestone that allows increased mass airflow and transformation from laminar system to turbulent system. In order to obtain a turbulent flow within the dynamic air vein of the heat exchanger channel **(**air/ground), in order to improve the quality of heat transfer between the transmitted air and the walls of the buried heat exchanger tube contact with the ground. (**Fig IV.19**) describing the evolution of air temperature in heat exchanger, we can see the flow effect on the thermal behavior of buried geothermal exchanger.

IV.2.5.c. Effect of diameter of pipe:

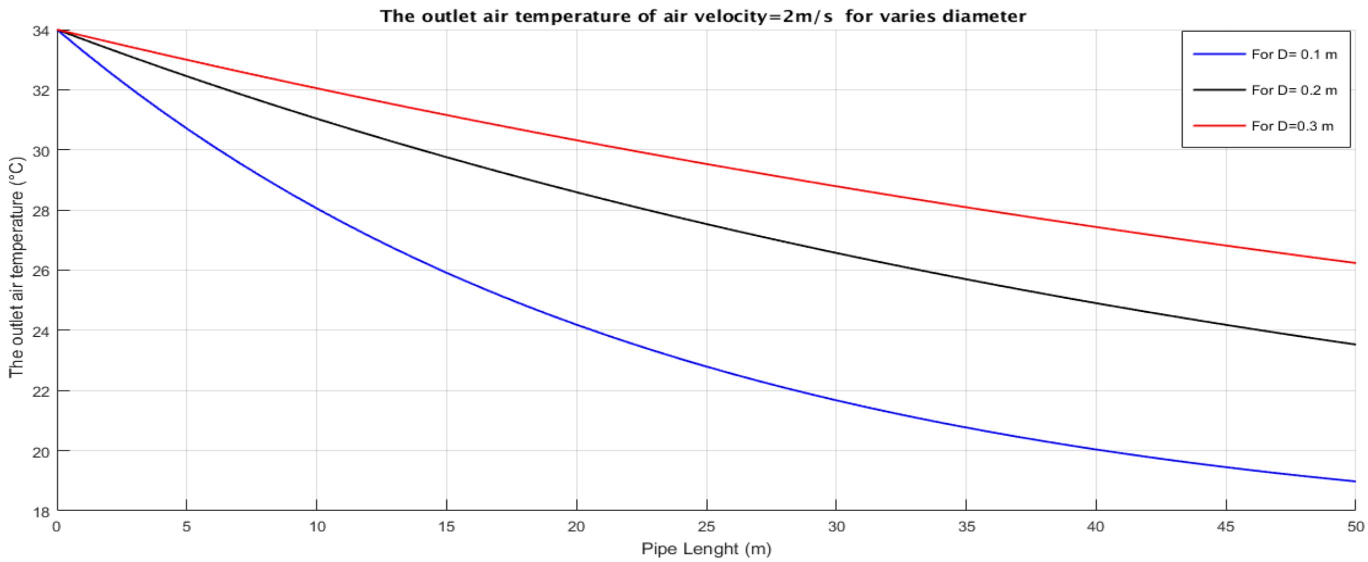


Fig.IV.20: The outlet air temperature of velocity =2m/s for varies diameter

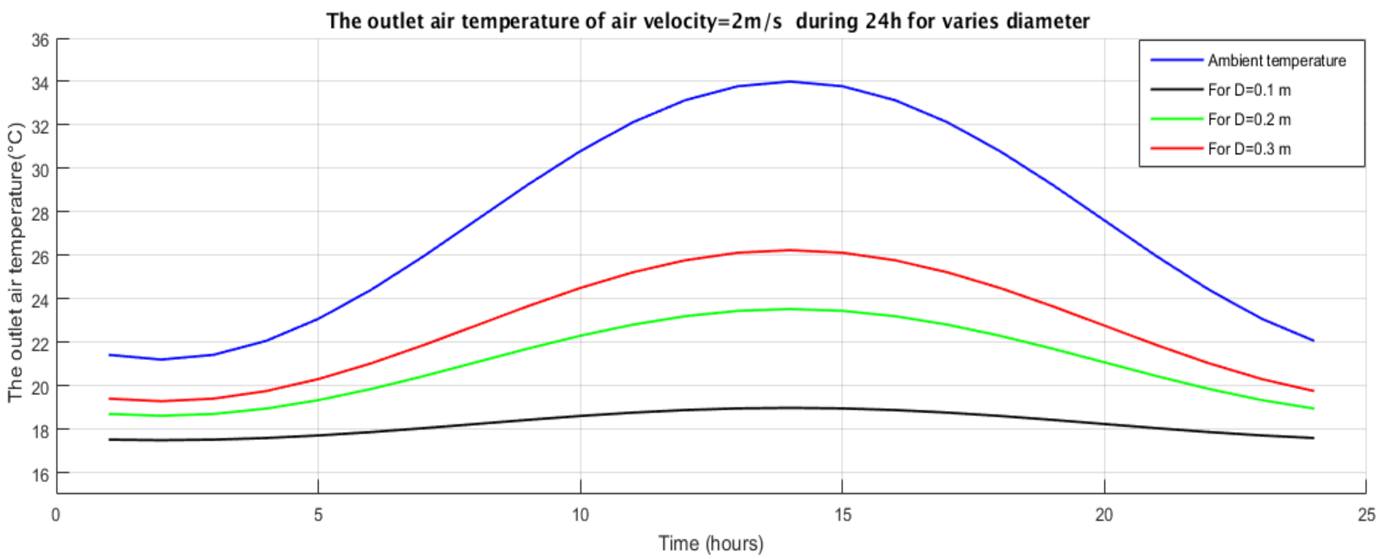


Fig IV.21: Ambient and outlet air temperatures (EAHE) system during 24h for varies diameter.

- **Figures (IV.1), (IV.13)** shows the influence of the diameter of the air tube, the number and diameter of the pipes determines the total part of the pipes through which the air will circulate, affecting the velocity of air flow and the seam surface between air and ground. Small diameter pipes give better thermal performance, but with a significant reduction in pressure confirmed (De Paepe & Janssens 2003).

- And finally, we can conclude that:

The buried tube performance was shown to increase with the increase in tube length. However, when the pipe length was established above 50 m, the outlet temperatures of the buried pipe remained the same, without any significant effect from increasing the pipe length.

As for air velocity (airflow), the best speed is 1m/s. When air speeds are higher than this, the low temperature between the buried pipe inlet and the port has become less.

As for the study when using a smaller size, pipes reduce the temperature inside the buried tube. The diameter of the small tube allows the heat transfer more efficiently and thus the temperature range closer to the surrounding soil temperature. The rationale behind this is when the diameter of the tube is small; in the center of the tube approaches the surrounding soil.

IV.2.6. Conclusion:

Climatic factors and the physical properties of the soil had an important impact on the temperature of the ground surface, especially the speed of wind and surface albedo. It is also worth noting the result obtained in the effect of the fractional cloud cover coefficient, where it was found that the ground temperature increases with the increase of the coefficient, and this phenomenon occurs at the level of the atmosphere where the cloud of greenhouse gases gathers and contributes to it to global warming. Which is known (**The Heat Dome**).

The factors affecting the heat performance of the (EAHE) are very important to consider when installing it.

Reference:

[1] Sedighi, M., Hepburn, B. D., Thomas, H. R., & Vardon, P. J. (2016). Energy balance at the soil atmospheric interface. *Environmental Geotechnics*, *5*(3), 146-157.

[2] Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated.

[3] http://www.weatherbase.com seen in 10/05/2022

[4] MABROUKI, D. (2014). *Étude de l'influence des paramètres climatiques sur la température du sol (application au site de Biskra)* (Master's thesis).

[5] SHARMA, Shweta, et al. Effect of urban surface albedo enhancement in India on regional climate cooling. *Remote Sensing Applications: Society and Environment*, 2017, 8: 193-198.

[6] https://fr.tutiempo.net/climat/2020/ws-605250.html seen in 12/05/2022

GENERAL CONCLUSION

This study is divided into two main topics related to each other. Several studies have been collected; the first section depends on the thermal energy balance of the ground-atmosphere interface that determines the temperature of the ground, where the modeling of soil temperature on any day of the year is based on the properties of the soil at the site and meteorological data. Knowing this greatly helps in facilitating energy applications, as we have noticed in the curve of the ground temperature, as the temperature was about 3 meters constant and varied with the ambient air temperature, so any change in the environmental parameters would affect this value. The second section is about the air temperature at the outlet of the system (EAHE). We have modeled the EAHE system and seen some of the effects of its properties. These results must be taken into account before it is actually accomplished. Climatic factors and the physical properties of the soil had an important impact on the temperature of the ground, knowing this greatly helps in facilitating energy applications, such as earth-air heat exchanger. The factors affecting the thermal performance of the (EAHE) are very important to consider when installing it.

Satisfactory results were obtained that can be compared with experimental works to find out their validity.

ملخص:

في هذه الدراسة، نقدم ماهية توازن الطاقة الحرارية على سطح الأرض مبينين العوامل المؤثرة في درجة حرارة الأرض، وذلك من خلال صياغة شروط الحدود السطحية بين التربة والغلاف الجوي حيث نأخذ في الإعتبار تدفق الحرارة عند واجهة التربة من خلال آليات: إشعاع الموجة القصيرة والإشعاع طويل الموجة والتدفق الحراري المحسوس والتدفق الحراري الكامن (الحرارة اللاطية). تم إدراج ذلك في نموذج رقمي على برنامج ماتلاب، مما يسمح بملاحظة تأثير المتغيرات المناخية والخصائص الفيزيائية للتربة مثل الإشعاع الشمسي ودرجة حرارة الهواء المحيط والرطوبة النسبية وسرعة الرياح وانعكاسية السطح وبياضه الخ على درجة حرارة الارض، ويمكن أيضا معرفة كمية التوصيل الحراري في الأرض وتدرُّج درجة الحرارة في العمق. بعد ذلك درسنا العوامل المؤثرة على مبادل حراري مدفون (هواء / أرض) للتدفئة الشتوية والتبريد الصيفي.

الكلمات المفتاحية: دراسة العوامل المؤثرة، توازن طاقة سطح الأرض، درجة حرارة الأرض، مبادل حراري (أرض /هواء)، النمذجة العددية.

Abstract:

In this study, we present what is the thermal energy balance on the surface of the ground, indicating the factors affecting the ground temperature, by formulating the conditions of the surface boundary between the soil and the atmosphere, where we take into account the heat flow at the soil interface through mechanisms: short-wave radiation and long-wave radiation, sensible heat flow, and latent heat flow. This was included in a digital model on the Matlab program, which allows observing the effect of climatic parameters and physical properties of the soil such as solar radiation, ambient air temperature, relative humidity, wind speed, surface emissivity and albedo, etc. It can also know the amount of heat conduction in the ground and the temperature gradient in depth. Next, we studied the factors affecting a buried Earth-air heat exchanger for winter heating and summer cooling.

Keywords: Parametric Study, Ground surface energy balance, Ground temperature, Earth-air heat exchanger, Numerical modelling.

Résumé:

Dans cette étude, nous présentons quel est le bilan énergétique thermique à la surface du sol, montrant les facteurs affectant la température du sol, en formulant les conditions de la limite de surface entre le sol et l'atmosphère, où l'on prend en compte la chaleur flux à l'interface du sol par des mécanismes: rayonnement à ondes courtes et rayonnement à ondes longues, flux de chaleur sensible et flux de chaleur latente. Celui-ci a été inclus dans un modèle numérique du programme Matlab, qui permet d'observer l'effet des paramètres climatiques et des propriétés physiques du sol telles que le rayonnement solaire, la température de l'air ambiant, l'humidité relative, la vitesse du vent, l'émissivité et l'albédo de surface, etc. Il peut également connaître la quantité de conduction thermique dans le sol et le gradient de température en profondeur. Ensuite, nous avons étudié les facteurs affectant un échangeur de chaleur enterré air-sol pour le chauffage en hiver et le refroidissement en été.

Mots clés: Etude paramétrique, Bilan énergétique de la surface du sol, Température au sol, Échangeur de chaleur air-sol, Modélisation numérique.