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Evaluation of the Techno-Economies Viability of a Geothermal Earth-to-Air Heat Exchanger (EAHE) System

Presented by students:

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Dedication

I dedicate this humble work:

To those who have showered me with tenderness since my birth.

Dear mother. To my dear father, kindred spirits all my friends;

To all my professors who helped me finish my work

To all my friends and colleagues in the Master II upgrade program

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Nomenclature

T_S : Average soil surface temperature [C°]

As : Ground area temperature amplitude [C°]

Z : Depth of the ground [m]

α : Diffusivity thermal [m2/s]

T : Temps [jours]

Tin : Temperature of the fluid at the inlet of the pipe [C°]

Tout : Fluid temperature at the outlet of the pipe[C°]

Cp : Capacity calorific [J/ (kg .K)]

dT : Temperature difference [C°]

Qc : cooling capacity (kWh)

r_1 : indoor radius of the tube [m]

r_2 : outer radius of the tube [m]

R conv : Linear thermal resistance corresponding to the convective exchange between the air and the tube wall [m2 K/W]

R pipe : Thermal resistance of the buried pipe [W/ m. K]

R soil : Thermal resistance between the tube and the cylindrical adiabatic surface [W/ m. K]

h conv : Convective coefficient of exchange [W/ m. K]

λ pipe : Thermal conductivity of the wall of the buried pipe [W/m. K]

λ soil : Soil thermal conductivity [W/ m. K]

Re : Reynolds number Dimensional

Nu : Nusselt number Dimensional

Pr : Number of Prandtl Dimensional

d : pipe diameter [m]

ε : Average efficiency [%]

m : masse[kg]

ρ: Volumic mass [kg.m-3]

A : Ara.[m2]

$\dot{m}$ eau : Mass flow of water [kg /s]

μ: Dynamic viscosity of the fluid [Pa. s]

V : Fluid velocity [m/s]

L : length pipe [m]

e : Pipe thickness [mm]

TWh: Terawatt hours
Ej: Exajoule
GWh: Gigawatt-hour
GW: Gigawatt
Kb/d: Thousand barrels per day
TEP: Tonnes of oil equivalent

Ktoe: Kilo tons of oil equivalent
°C: Degree Celsius
EAHE: Earth-Air Heat Exchanger
kWh: Kilowatt-hour
kW: Kilowatt
CO_2 : Carbon
Dioxidem^3: Cubic
Meter MW:
Megawatt
PV: Photovoltaic
RE: Renewable Energy
HVAC: Heating, Ventilation, and Air Conditioning
RES: Renewable Energy Sources
IEA: International Energy Agency
EIA: Energy Information Administration

UNFCCC: United Nations Framework Convention on Climate Change

IPCC: Intergovernmental Panel on Climate Change

INTRODUCTION GENERALE

INRODUCTION GENERALE

Recently, energy consumption in Algeria, in the local sector, and other sectors, represented in building sector 46%, followed by the transportation sector at 30.6%, and finally the industrial sector. Construction work increased by 22.7% in 2019, and per capita, final energy consumption increased from 4,697,843 terawatt-hours per person during the period from 2004 to 2007 to 5,124,566 terawatt-hours (TWh), an increase of 4%. Between 2012 and 2007, the growth rate remained almost constant at 1.73% in 2023.

Witnessed a significant increase in energy prices, prompting us to seriously consider harnessing renewable and unlimited energy sources such as solar radiation. The HVAC system is an essential part of the energy consumption of buildings, accounting for about half of their energy consumption. Hence, the importance of achieving efficient systems for heating, ventilation, and air conditioning (HVAC), such as the use of heat pumps. However, improving HVAC systems alone is not enough; we must also look into fully utilizing environmental technologies in the building design phase. We need to focus on reducing heating and cooling loads to the lowest possible levels using renewable energy and modern techniques. This introduction marks the beginning of our research journey, where we will discuss in detail how to achieve our goals of reducing energy consumption and providing thermal comfort and a sustainable environment in buildings.

The current high demand for energy consumption in Algeria is mainly due to the increase in the living standards of the population and the resulting comfort, in addition to the growth of industrial activities. In Algeria, the construction sector is the most energy-consuming. Thermal comfort inside buildings is a fundamental requirement for ethical and physicalbehavior. It is primarily estimated according to external climatic standards. In semi-arid and arid regions like the El Oued region, heating needs in winter are low, though real, but cooling needs in summer are much greater Traditional homes offer solutions to climatic adaptation problems, but existing homes must also meet the requirements of modern life. Traditional cooling systems need to be repaired and improved to adequately meet thermal comfort requirements in buildings in arid areas. Natural ventilation is one of the methods that used to be employed in the engineering of traditional cities in southern Algeria. Palaces and ancient cities are living examples where balance and harmony with the climate are essential elements in their formation. To reduce electricity usage for air conditioning devices, passive cooling techniques have become more attractive in recent years, justifying their exploitation in variousforms.

Ventilation and cooling, relying on renewable energy available abundantly in the earth's heat. The system mainly consists of a heat exchanger, known as a heat exchanger, which transfers heat between indoor air and pipes buried under the ground surface. When installing an EAHE system, outside air is passed through a network of pipes buried under the ground surface. In summer, outside air is cooled through the heat exchanger as it passes through the buried pipes, where excess heat is absorbed from the earth. Then, the cooled air is transferred indoors, creating a comfortable environment for residents in an eco-friendly manner. In winter, cold air is heated through the heat exchanger as it passes through the buried pipes, converting the heat stored in the earth into indoor air. Thanks to this intelligent system, energy consumption efficiency in the building is significantly improved, contributing to achieving thermal comfort efficiently and sustainably.

This document contains three chapters of work. The first chapter provides the global and national context of energy, especially energy consumption in the construction sector, to understand the thermal behavior of building structures.

As for the second chapter, an analytical model will be established to estimate the distribution of soil temperature using the heat transfer equation, and the thermal and energy performance of the geothermal heat exchanger and its efficiency will be evaluated, in addition to the pressure drops resulting from airflow.

As for the third chapter, an overview will be presented on the role of buried heat exchangers in geothermal energy systems, evaluating their efficiency in various climatic environments, focusing on the heat exchange rate and other factors such as airflow and burial depth

General Information Of geothermal energy

I General information on geothermal energy

I.1. Introduction

The buildings sector stands out globally as one of the most energy-intensive sectors. Factors contributing to the increasing energy consumption in housing include rapid population growth, a surge in housing units, decreasing costs of traditional energy sources, and widespread adoption of electrical appliances in households. This chapter offers an extensive overview of global and Algerian energy consumption trends. It delves into the potential of geothermal energy and other clean, renewable energy sources, with a specific focus on geothermal applications. The discussion highlights the utilization of heat exchangers, such as Canadian wells, which facilitate both heating and cooling in buildings by exchanging heat between the air and the ground. Furthermore, the chapter provides climatic data for Algeria and the El Oued region and showcases various types of heat exchangers.[1].

I.2. Global energy demand

Primary energy demand growth slowed compared to 2021, increasing 1.1% (6.6 Exajoules) in 2022 versus 5.5% (30.9 EJ) in 2021. Primary energy in 2022 was 16.6 EJ above 2019 pre-COVID levels with consumption increasing in all regions Except for Europe (-3.8%) and the Commonwealth of Independent States)CIS) (-5.8%), Primary energy consumption in non-Organisation for Economic Co-operation and Development countries (OECD) increased by 20.5 EJ compared to their 2019 pre-COVID levels, driven largely by growth in China (14.6 EJ) accounting for 72% of the increase. Primary energy demand in OECD countries was slightly down against 2019 levels at 234 EJ in 2022 versus 238 EJ in 2019. The increase in primary Energy supply between 2019 and 2022 was largely driven by renewable (excluding hydro) energy sources (13.5 EJ) and coal (10.6 EJ), with increased gas production (2.7 EJ) also evident. And coal (10.6 EJ), with increased gas production (2.7 EJ), Primary energy use in 2022 was 2.8% above 2019 levels [1].

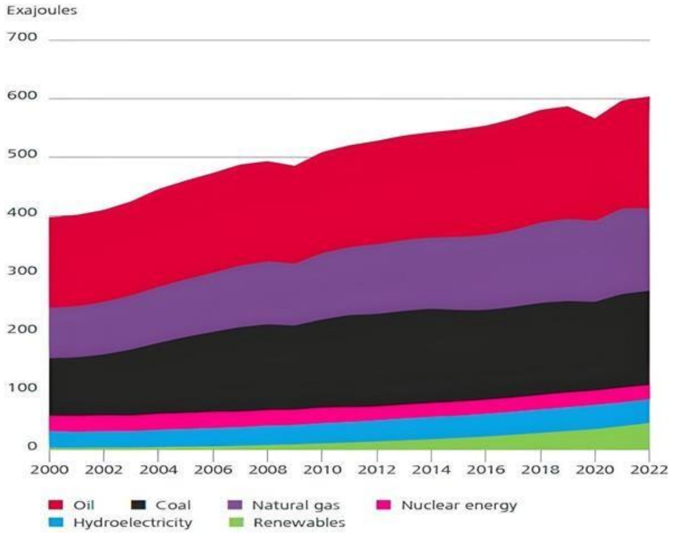


Figure I.1: World energy consumption [1]

I.3. Energy Consumption across Different Energy Forms

Despite the international community's determination to reduce carbon emissions - that is, to prefer using low-carbon energy sources that emit fewer greenhouse gases - the demand for primary energy has increased by more than 52% since 2000 until 2022. Hydrocarbon derivatives remained dominant at a rate approaching 87%, as shown in the graph. Fossil fuels top the list, with petroleum accounting for 33%, followed by coal at 27%, and natural gas accounting for about 24% of primary consumption. Meanwhile, production from renewable sources, led by hydroelectric power at 7%, exceeds nuclear energy production (4% in 2014). Global primary energy consumption reached around 583 Ej in 2019. A significant portion, amounting to 40% of primary energy consumption, is allocated to electricity production [2]

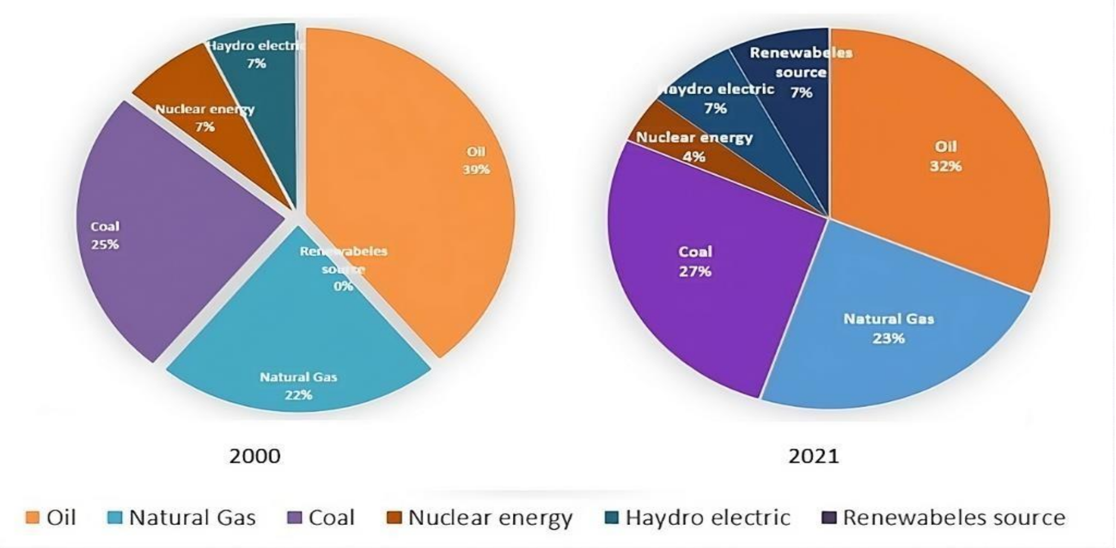


Figure I. 2: Breakdown of the overall output of primary energy by form of energy (2000 - 2021) [2]

I.4. National Energy

I.4. 1 Energy production in Algeria

The surge in natural gas production (+24%) is pivotal, fueled by enhanced device performance, Human Resource Management (HRM) boosting service deployment, and adoption of new technologies. These efforts are synergized with rising European demand for Algerian gas.

Petroleum production saw a modest uptick of 1% to meet Algeria's increased quota within the Organization of the Petroleum Exporting Countries (OPEC+) framework, scaling from 900 Thousand Barrels per Day (KB/d) in 2020 to 911 KB/d in 2021.In the realm of renewable energy, primary electrical production (RE) registered at 662 GWh, marking a 4.1% decline from 2020 levels. This decrease stemmed primarily from:

- Hydroelectric facilities (-81%), plummeting from 49.6 GWh in 2020 to 9 GWh in 2021 due to unfavorable precipitation patterns;
- Photovoltaic installations (-3.5%), slipping from 665 GWh in 2020 to 642 GWh in 2021, attributed to technical issues ,In the commercial energy landscape, natural gas remains the dominant player, comprising 60% of primary energy production, followed by petroleum at 29%, as depicted in the figures.

The primary energy production in the commercial sector is largely dominated by natural gas, making up 60% of the total. Petroleum follows, contributing 29% to the energy mix[3]

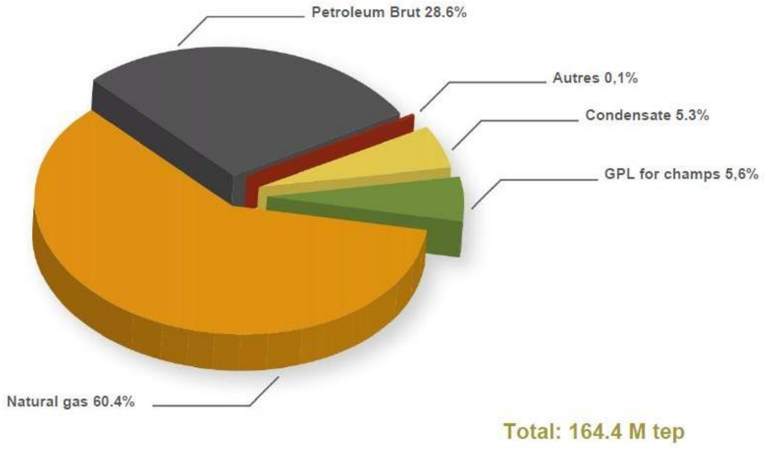


Figure I. 3: Structure of the primary production [3]

I.4. 2 Production energy delivery

The energy production surged by 8.2% in 2021, reaching 67.2 million, largely fueled by a 13.1% increase in electrical output and a 14.1% rise in liquefied natural gas. This uptick is credited to the revival of economic activities, rebounding to pre-pandemic levels, coupled with a gradual easing of health measures. Despite the lack of a detailed breakdown of energy production, petroleum products persist as the dominant component in the energy composition, comprising 43% of the total mix

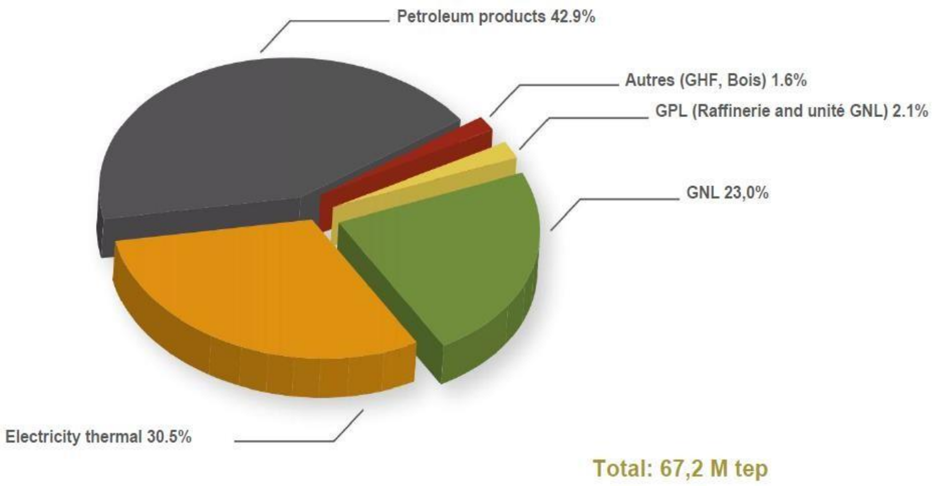


Figure I. 4: Structure of the Production energy delivery [3]

Primary energy production means the production of primary energy, which is energy extracted directly from natural sources such as coal, oil, natural gas, solar energy, wind, and others. "Production energy delivery" refers to delivering the produced energy, which is the process of converting primary energy into various forms of energy such as electricity or fuel used in transportation or heating. This energy can be used for both domestic consumption and export [3].

I.5. Energy consumption in Algeria

Energy consumption in Algeria depends on a variety of factors, including economic growth, industrial development, lifestyle, and government policies related to energy. Although Algeria is an energy producer thanks to its abundant natural resources, it faces challenges in meeting its increasing energy needs and improving its consumption efficiency.

Algeria relies heavily on oil and natural gas as primary sources of energy. The country is experiencing an increase in energy demand due to economic growth, population increase, and shifts in the industrial and domestic sectors. Steps are being taken to encourage energy efficiency and the adoption of renewable energy sources such as solar, wind, and geothermal to reduce dependence on fossil fuels and decrease harmful emissions.

The government implements policies to encourage sustainability and energy efficiency, including promoting awareness of energy conservation and the use of renewable energy sources. The government is also striving to improve energy infrastructure and promote international cooperation in this field. The national energy consumption (including losses) reached 67.2 million tons of oil equivalent in 2021, reflecting an increase of 7.7% compared to 2020, which was due to an increase in final consumption (8.0%), and saw a rise in consumption by energy industries as well as non-energy industries by 6.9% and 8.4% respectively.

In 2023, the energy market in Algeria is expected to register a compound annual growth rate of over 8.5% for the period 2020-2025. Algeria intends to obtain 37% of its installed capacity and 27% of electricity production dedicated to domestic consumption from renewable energy sources by 2030. The length of the electricity transmission network in the country reached 100% in 2019, representing an increase of 240% compared to its length in 2000. The state allocated 260 billion dinars (about 1.93 billion dollars) to rationalize energy consumption by 10% by 2030. Algeria consumed about 18.1 million tons (approximately 128.5 million barrels)of oil derivatives during the past year (2023), registering an increase of about 3.5% compared to the previous year[3, 4]

I.5.1 Energy consumption by product:

In recent years, Algeria has witnessed significant changes in energy consumption. Natural gas consumption saw a strong increase of 17.4%, reaching 16.0 million tons of oil equivalent, making it the primary source of energy used and reinforcing its position as a key factor in the final energy mix by 33.3%. This increase reflects the growing demands of SONELGAZ customers, especially concerning buildings.

On the other hand, the consumption of petroleum products accounted for 32.2% of final consumption, representing 15.5 million tons of oil equivalent, following a slight recovery of 1.2% in daily petroleum product consumption after two years of decline.

Electricity consumption also increased by 4.9%, reaching 13.9 million tons of oil equivalent, due to the increased demand from SONELGAZ customers. Finally, the demand for Liquefied Petroleum Gas (LPG) witnessed an 11% increase, reaching 2.6 million tons of oil equivalent, due to the increased consumption of LPG.

With Algeria's focus on enhancing the use of renewable energies, it is expected that the country's energy market will experience significant growth. It is anticipated that the compound annual growth rate will exceed 8.5% for the period from 2020 to 2025. The state aims to obtain 37% of installed capacity and 27% of electricity production for domestic consumption from [3, 4]

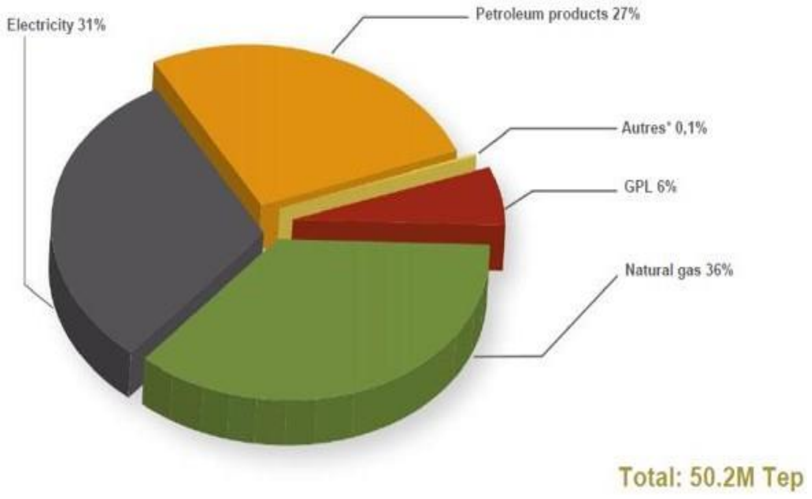


Figure I. 5: Breakdown of final consumption by energy product [3]

I.5.2 Energy consumption by sector:

In 2022, energy consumption in Algeria underwent significant developments across various sectors: In the "buildings and others" sector, demand rose by 6.2% from 22.1 million tons of oil equivalent in 2020 to 23.4 million tons in 2021. This increase was primarily fueled by a 5% surge in the residential subsector and a notable 13.5% uptick in the tertiary and other subsectors. The "Transport" sector witnessed a recovery of 7.6%, climbing from 13.5 million units in 2020 to 14.5 million units in 2021. This growth was driven by heightened consumptionof land and air fuels, including a 5.1% increase in diesel oil usage, a 35.8% surge in liquefied petroleum gas, a 1.8% rise in gasoline consumption, and a notable 15.1% uptick in aircraft fuelusage. This increase was concurrent with a rise in land transport consumption and the gradual reopening of airspace. The "Industries" sector experienced a substantial 12% rise in consumption, reaching 12.2 million tons of oil equivalent in 2021. This surge was attributed tothe resumption of economic activities, particularly driven by small, medium, and microindustries, as well as the agri-food, chemical and building materials sectors.

These developments underscore Algeria's efforts to reduce its dependence on fossil fuels and promote the use of renewable energies. The government has committed to achieving 37% of its installed capacity and 27% of electricity production for domestic consumption from renewable sources by 2030. It is anticipated that renewable energy will play a dominant role in Algeria's energy market [3].

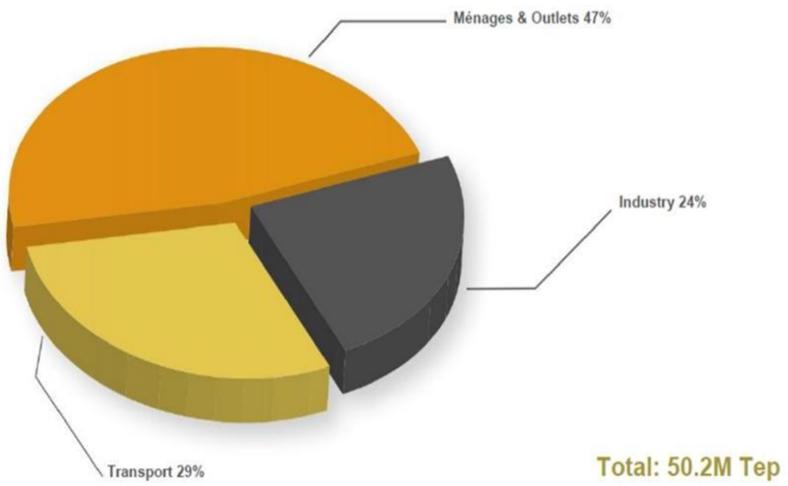


Figure I. 6: Energy consumption in Algeria by sector 2021[3]

I.5.3 Natural gas and electricity consumption

A. Natural gas

Algeria stands as a gas powerhouse in Africa and holds a prestigious position on the global stage. In 2021, Algeria witnessed significant developments in the natural gas sector, with production reaching around 100.8 billion cubic meters, demonstrating its immense and growing production capacity.

On the consumption side, Algeria used about 44.3 billion cubic meters of natural gas that year, reflecting the importance of this natural resource in meeting domestic needs and supporting economic growth.

In terms of exports, Algeria achieved a growth of 7.8%, reaching 11.48 million tons of liquefied natural gas. The vast majority of these exports were directed to European markets, reaffirming Algeria's strategic role in securing energy supplies for the old continent.

Figure I. 7 shows case the strength and resilience of the natural gas sector in Algeria and provides a glimpse into the country's significant potential in this field. With ongoing investments and development, Algeria is expected to continue enhancing its position as a major provider of natural gas globally [3, 4].

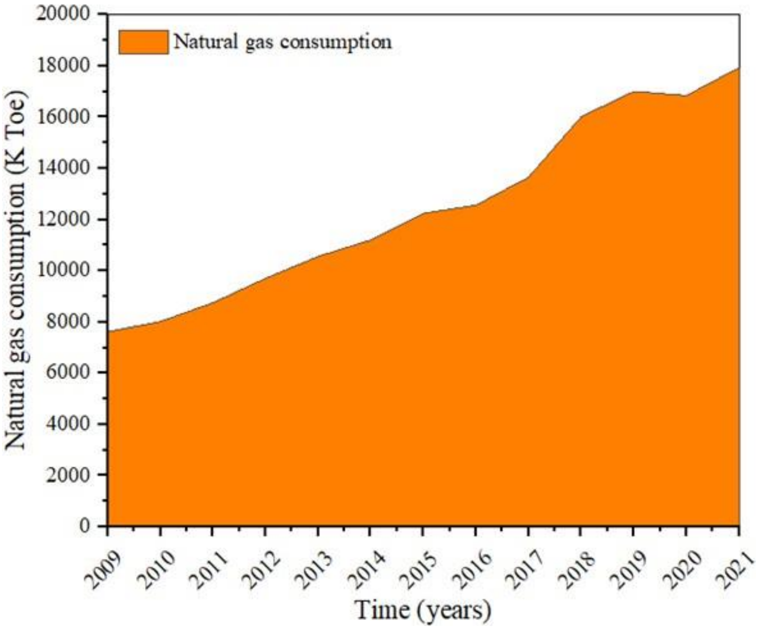


Figure I. 7: Evolution of national naturel gas consumption in the buildings sector[3, 4]

B. Electricity

In 2021, Algeria experienced significant developments in the electricity sector. The electricity demand reached approximately 16,224 megawatts, reflecting the country's continuous growth in energy needs Algeria's energy-producing capacity is around 21.4 GW, mostly from natural gas and combined cycle power plants. Algeria aims to become a global competitor in the renewable energy market, targeting 15,000 Megawatts of renewable energy capacity by 2035. As for renewable energy, it constitutes about 3% of the country's energy mix, and Algeria possesses tremendous potential in this area, especially solar energy, with more than 240 thermal springs. In terms of access to electricity, nearly 100% of the population in Algeria enjoys access to electricity. SONELGAZ, the national company for electricity and gas, has ambitious plans to develop its production capacities and improve service levels. These plans include enhancing the country's infrastructure in both electricity and gas. Plans involve developing electricity and gas distribution networks to meet the increasing demand [3, 4].

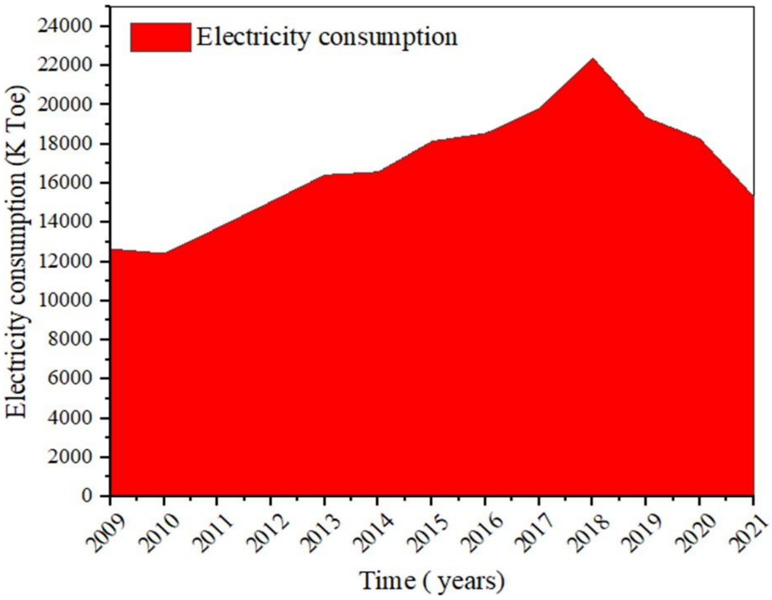


Figure I. 8: Evolution of national electricity consumption in the buildings sector[3, 4]

I.5.4 Consumption of electricity in the El Oued region

The consumption of electrical energy in the region of El Oued has led to a steady increase over the past years, reaching 1 billion kilowatt-hours in 2017, 1.1 billion kilowatt-hours in 2018, 1.2 billion kilowatt-hours in 2019, and rising to 1.4 billion kilowatt-hours in 2020. Continuing with the developments, it is evident that the demand for energy in the region of El Oued is steadily increasing year after year. With the temperatures rising significantly in the region, the use of air conditioning is increasing notably, leading to an increased demand for electrical energy during the summer season. Consequently, recent studies anticipate that the energy demand will continue to rise soon, necessitating the expansion of infrastructure and development of production capacities to meet this growing demand [5].

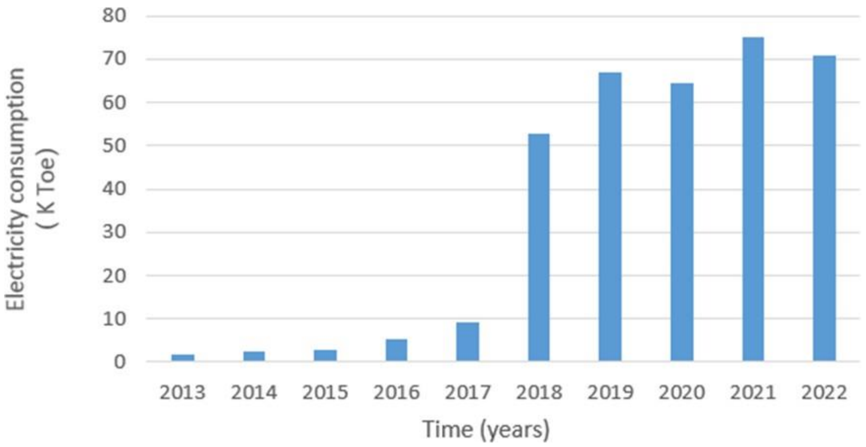


Figure I. 9: Evolution of Electricity Consumption in El Oued [5]

I.6. Climatic Data

Geographical data Algeria is characterized by a variety of climatic zones that can be divided into 4 categories:

- Zone A: Marine coastline;
- Zone B: Behind the mountain coast;
- Zone C: Highlands;
- Zone D: Pre-Saharan and Saharan.

The marine coast enjoys a particularly temperate climate, due to the moderating action of the sea. Characterized by mild and rainy winters, and hot and humid summers with low amplitudes.

Algeria is located between latitude 18° and 38° north, and longitude 9° west and 12° east, with an international longitude of 0° Greenwich passing near the city of Mostaganem. Distances between north-south and east-west vary from 2,000 to 1,600 km, respectively.

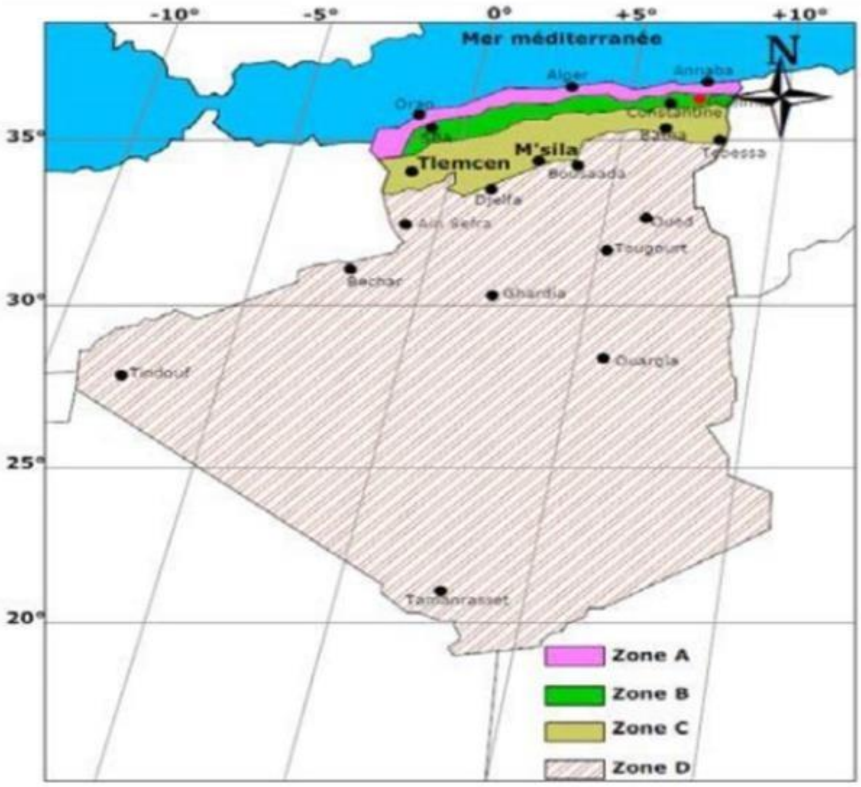


Figure I. 10: Classification of climate in Algeria [6, 7]

The thermal behavior of a building depends on external pressures such as outside air temperature, radiation exchange with its surroundings, and mass transfer. The building consists of elements connected to each other and heat is transferred simultaneously by conduction, intersection and radiation [6, 7].

I.6.1 Climate of the El Oued

El Oued Province is one of the Algerian states located in the southeast of the country and enjoys a desert climate. Average temperatures in summer range between 41 °C during the day and 23°C at night, while in winter they range between 10 °C during the day and 1°C at night. The state receives a small amount of rainfall, not exceeding 49 mm on average annually, and it falls mainly in November and December. Wind speed is average, about 5.6 m/s, and increases in the spring. Humidity is low about 28% and decreases further in the summer [8].

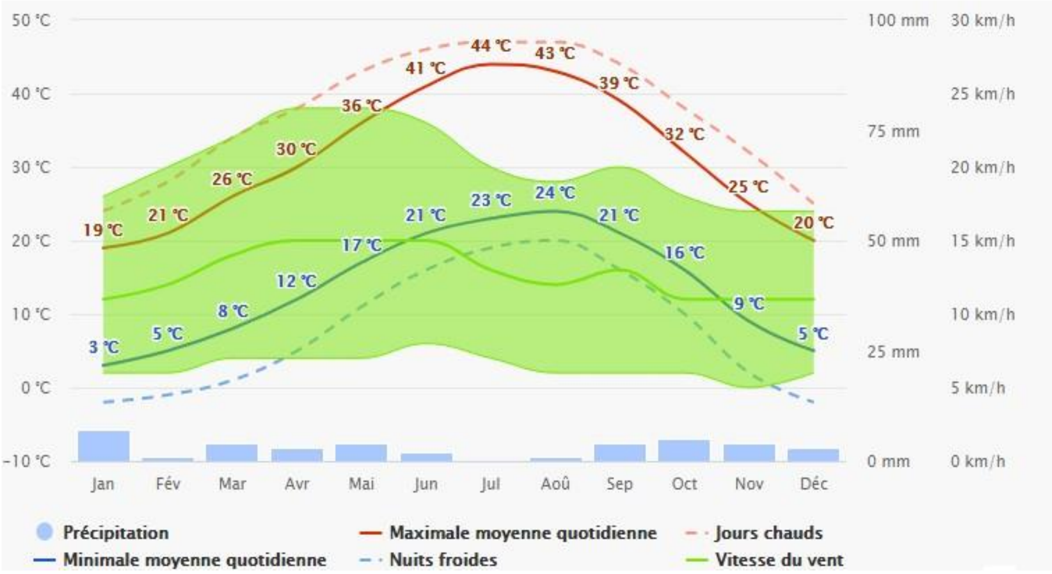


Figure I. 11: Interpretation of climatic data from the El Oued region [8]

I.7. Geothermal Energy

Geothermal energy is renewable energy extracted from the Earth's internal heat. According to the European renewable energy Directive 2009, geothermal energy is defined as “energy stored as heat beneath the solid surface of the Earth.” This energy is distributed evenly throughout the Earth, and increases at an average rate of 3 degrees Celsius per 100 meters of depth. The value of this rate varies depending on geological factors such as age, composition, and rock structures. Geothermal energy can be utilized in different ways, depending on the temperature and quantity available. One of the most important uses is electricity generation by geothermal conversion plants. Geothermal energy can also be used to provide heating and cooling for residential, commercial and industrial buildings, whether at the individual or community level. In addition, geothermal energy is used in some agricultural and biological activities such as heating greenhouses and raising fish and shrimp. The first use of geothermal energy dates back to the 19th century, when it was used for heating and bathing. Since then, geothermal technologies and applications have evolved significantly, and it has become one of the most important renewable energy sources in the world. In 2019, electricity production from geothermal energy amounted to about 92 GWh, distributed among 29 countries. This production is expected to increase in the future with improved efficiency, reduced costs, and increased investments. Geothermal energy is a sustainable and environmentally friendly source, as it uses the Earth's natural heat instead of burning fossil fuels, thus reducing greenhouse gas emissions and air pollution. It also provides continuous, reliable power that can respond to changing electricity demand at any time of the day or night. Moreover, geothermal energy contributes to enhancing the energy security of countries that possess geothermal resources and reduces their dependence on external imports of fuel [9-13].

A. Geothermal energy is divided into four categories

Geothermal energy relies on the heat generated from the Earth's interior and stored in its various layers. The temperature, depth, and geographical location of these layers vary, leading to their classification into four main categories.

The objective of this program is to produce 22 GW of renewable energy electricity by 2030, of which 12 GW will be devoted to national demand and 10 GW to export. This program focuses on the development of photovoltaic and large-scale wind energy, the introduction of biomass (waste valuation), cogeneration, and geothermal energy, and the postponement of the development of solar thermal energy (CSP) until 2021. The completion of **Figure I.8** will make it possible to achieve, by 2030, a share of renewables of almost 27% in the national electricity production balance sheet.

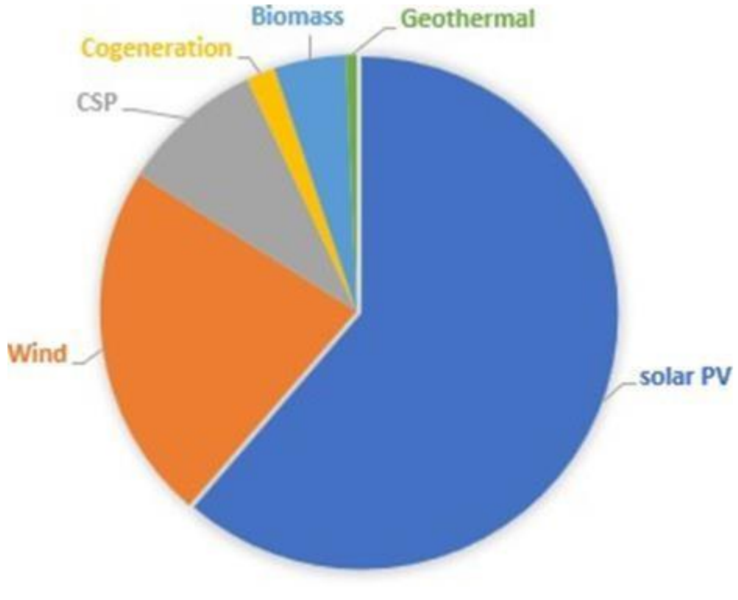


Figure I. 12: Distribution of the National Renewable Energy Program[1, 14]

I.8. Types of operation and application

The exploitation of geothermal energy generally depends on the temperature of the subsurface, which in turn depends on the depth at which the heat exchangers will be installed. The minimum depth (also known as minimum production depth (km)) is the depth that corresponds to a surface temperature of approximately 40°C. The map of the minimum depth of production in the world is represented in Figure I.9, and it is clear from this figure that the minimum depth of production in Algeria is between 1 and 1.5 km [15].

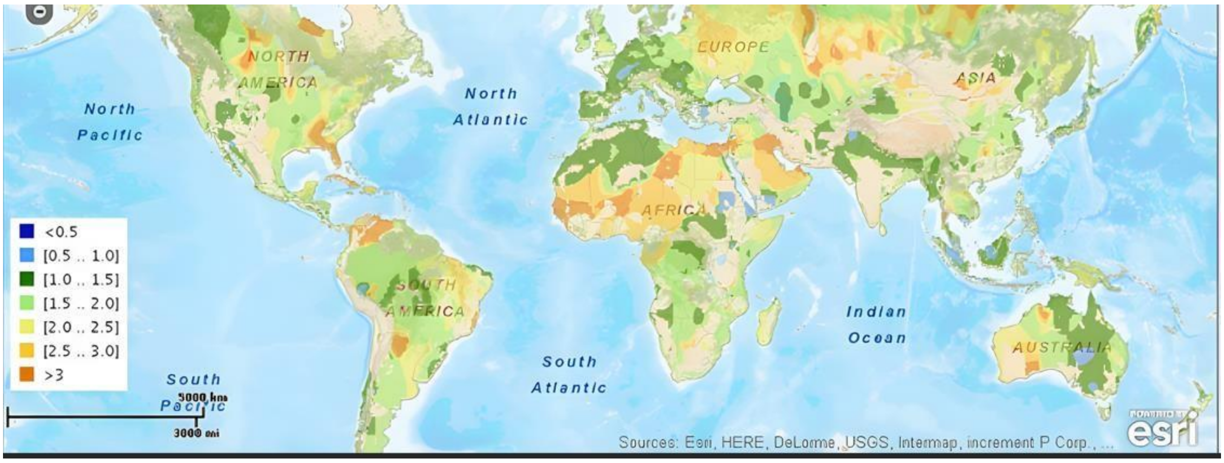


Figure I.11: Map of minimum production depth[15]

I.9. Geothermal energy potential in Algeria

The exploitation of geothermal energy is an essential part of renewable energy sources in Algeria, and has a wide variety of uses. These uses range from direct, such as fish farming, greenhouse heating, and bathroom treatments, to industrial uses, such as generating electrical power. Geothermal energy resources in Algeria are considered to be of low-energy type, and are mainly concentrated in the northern regions and in the Sahara [15].

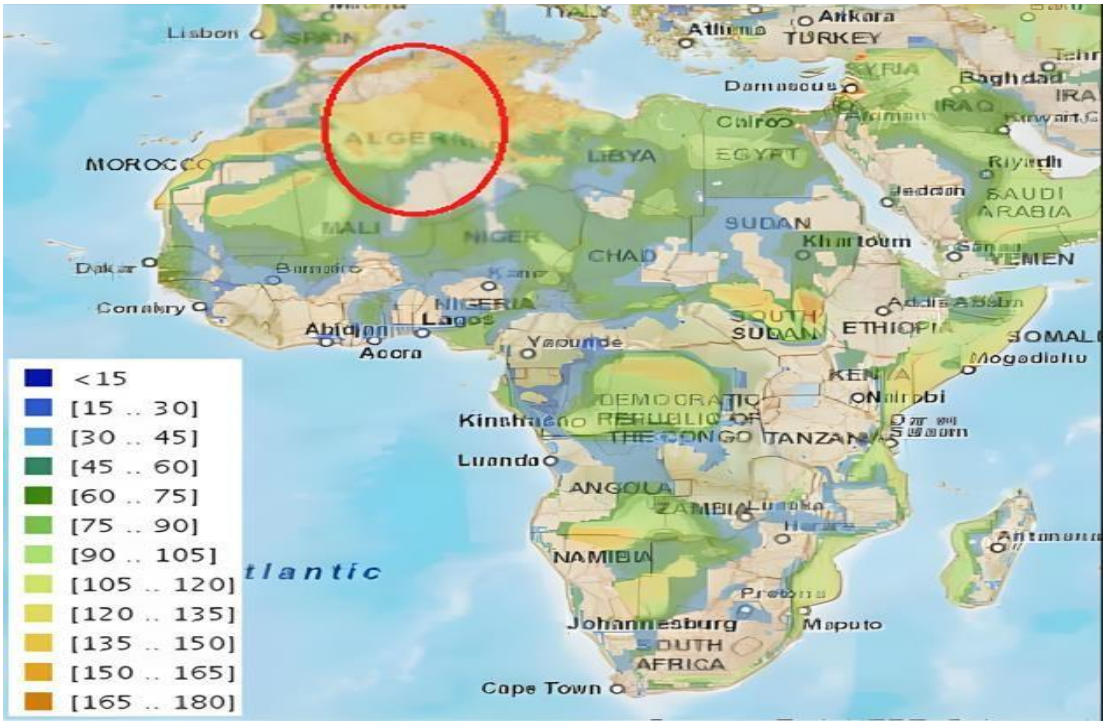


Figure I.12: Minimum production depth map [15]

The maximum temperature extracted to a depth of 3 km or less is shown in Figure I.11 for Algeria, and as can be seen in Figure I.12, Algeria shows excellent geothermal potential compared to other African countries. For example, the maximum temperature extracted for a depth of less than or equal to 3 km ranges between 100-150 °C[15].

A research team headed by Gourah et all [16]and others prepared a geothermal climate map showing the change in temperature as a function of depth over the Algerian national territory. Three areas with a strong thermal tendency have been highlighted: in the north-east, especially in the Constantine regions, and in the north-west (the Oran regions), in addition to many thermal springs in southern Algeria and precisely in the south-west. In these areas, the geothermal tendency can reach 7 °C per 100 m.

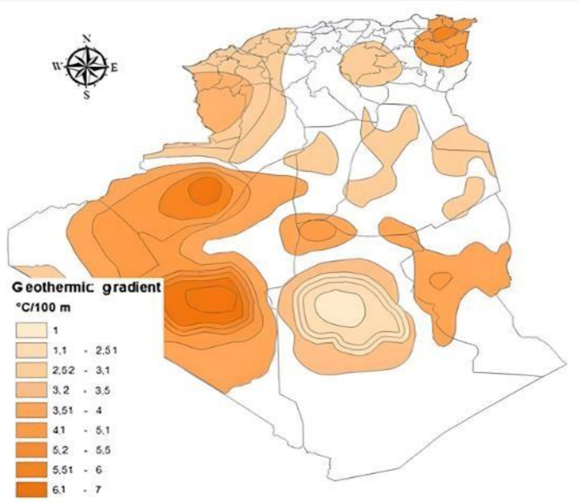
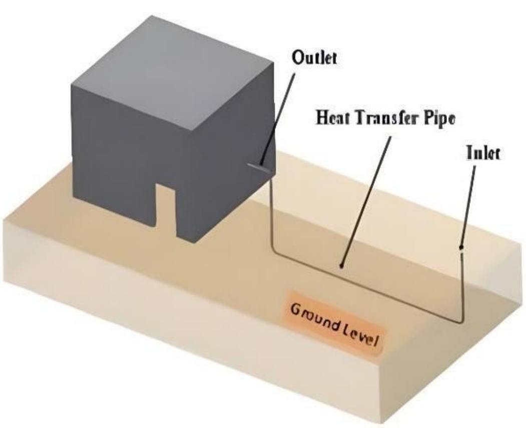


Figure I.13: Geothermal gradient map in Algeria [16]

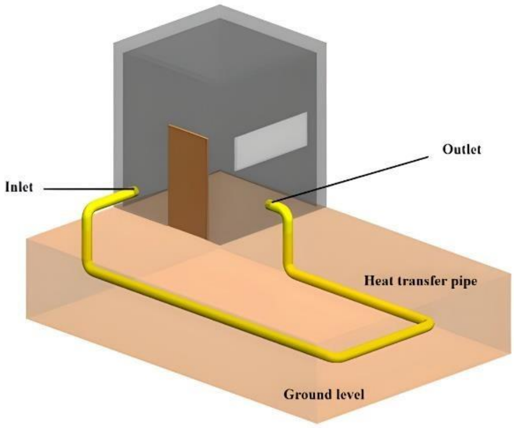
I.10. Types of heat exchangers

It varies Exchanges the heat from the earth to air in two type’s two main ones. Type the first Known As "the loop Open" where the Complete Reception Air External from during pipes To ventilate the Building, Type the second So he is called "the loop closed" where the Complete Reception Air from inside the Building before that Complete Rotate it from during Pipes. Uses Type the last in a way less in the Residential sector because it does not meet Quality requirements Air required. Aspects of the mission that Determine the efficient exchange the heat from the earth to the Air Include nature of the climate, and physical characteristics of the soil, And depth of a rock source, And the level of Subterranean water. Availability this is amazing information on the basics of designing System exchanger Air and the earth effectively. In addition to that, there is a hybrid System used in a common way Known As the "mixed system", which complete to merge exchanger the heat from the earth to Air with Air conditioning systems To reduce energy consumption and more the efficiency of the system. Maybe to merge Techniques Renewed For energy with exchanger the heat from the Earth to Air like constellations Wind And Chimneys Solar And others. See the figure (write the figure number below) [4, 17]

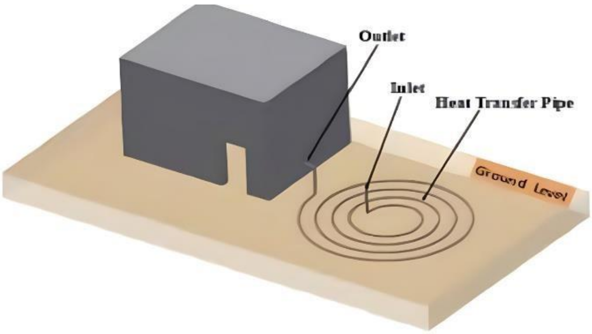
1. Classification of Buried Pipes:
   - Single-tube System;
   - Multiple-tube System.
2. Types of Buried Pipe Installation:
   - EAHE my head;
   - EAHE Spiral.
   - EAHE Horizontal;



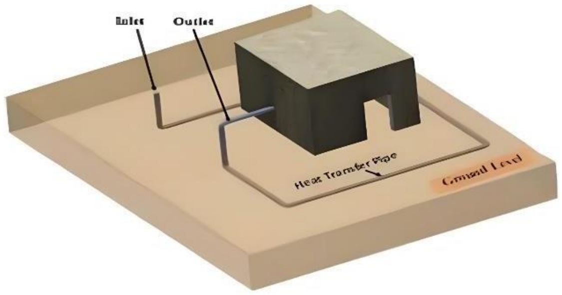
(a) Linear pipe-layout for EAHE systems



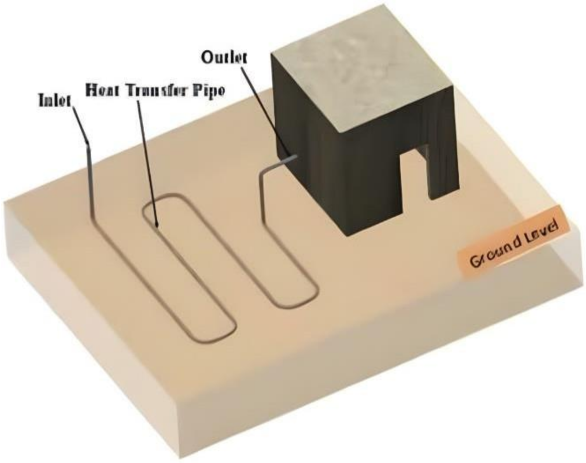
(b) Closed loop for EAHE system



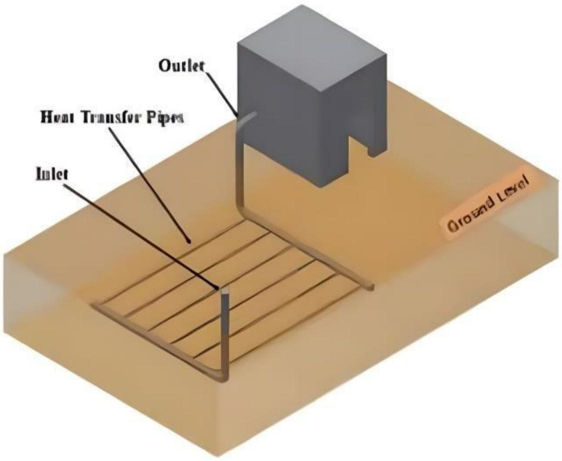
(c) EAHE systems with spiral pipe layouts



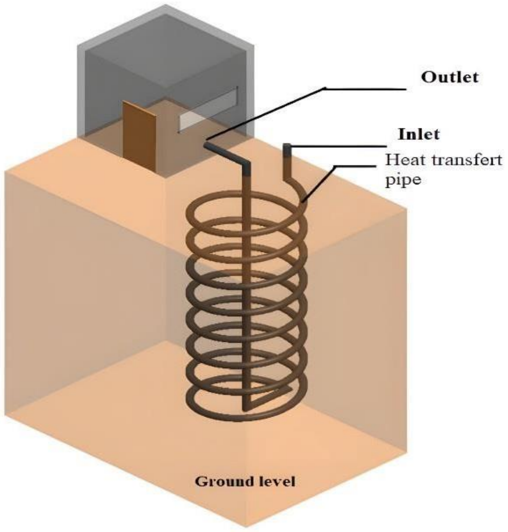
(d) Ring pipe-layout for EAHE systems



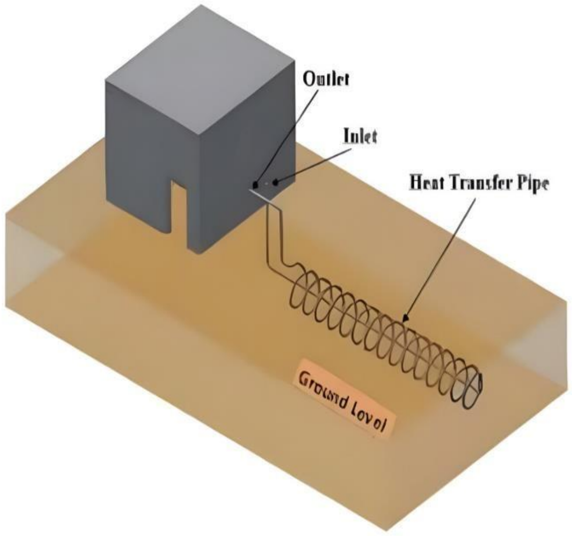
(e) Grid pipe-layout for EAHE system



(f) Serpentine pipe-layout for EAHE systems



g) Helical vertical-coil pipe-layout for a EAHE systems



(h) Helical horizontal- coil pipe layout for a EAHE

I.11. Advantage and disadvantage of EAHE

I.11.1 The Advantages

- Easy to design and install.
- It consumes less energy to operate the system;
- Adapts to a variety of soil types
- Requires less maintenance and lower costs
- No pollution or global warming from lack of combustion.
- Air is used as the working fluid.
- It has a simple design and therefore requires less maintenance.
- It does not require placing the unit in an open place to expose it to weather factors.
- Does not require energy consumption to operate in high wind speeds
- Lower initial costs than ground source heat pump systems and reflector air heat exchangers

I.11.2 The Disadvantages

- The installation price is considered high.
- Condensation breeds indoor air contaminants.
- The air outlet temperature is not homogeneous.
- Weather affects noise from above-ground exchanger pipes reaching living areas.
- Draining condensed water vapor from the air-ground heat exchanger is a problem. A useful solution to solve this problem in an underground wind tunnel is to pump any water into the

pipe, for example a small submersible pump can be placed at the lowest point. However, these solutions can increase the overall power consumption of the system[4, 18, 19]

I.12. Conclusions

After a comprehensive review of energy topics and their consumption globally and domestically, it becomes evident that the building sector remains one of the most energy-intensive sectors. This high consumption is attributed to several factors, including rapid population growth, increasing housing units, declining prices of traditional energy sources, and the proliferation of electrical appliances in households.

Mathematical Modeling

I. MATHEMATICAL MODELING

II.1. Introduction

The assessment of the efficiency of a geothermal heat exchanger involves the use of suitable thermal models. In the first part of this chapter, we will establish an analytical model using the general heat transfer equation under transient conditions to estimate the temperature distribution of the soil. In the second part, we will evaluate the energy and thermal performance of the geothermal heat exchanger, as well as the efficiency of the heat exchanger and the pressure drops resulting from the airflow controlling the heat transfer

II.2. Mathematical modeling

The geothermal heat exchanger (EAHE) essentially consists of a tube embedded in the ground. In thermal analysis, the geometric parameters of the buried pipe are: length, inner diameter and thickness. The equation that determines the difference in air temperature along the air temperature on the floor The exchanger takes the following parameters into account:

- Temperature in the soil
- Outlet temperature (ambient air).

II.2.1 Modeling of the soil temperature

The geothermal heat exchanger (EAHE) uses soil as a thermal medium to exchange heat with air The mathematical model for soil temperature is based on the principle of thermal conductivity applied to the material (air inside the pipe - pipe - soil).[20-23]

The equations of the temperature soil are given by the following relationship:

$$\frac{\partial^2 T}{\partial Z^2} - \frac{1}{\alpha} * \frac{\partial T}{\partial t} = 0 \quad \text{(II.1)}$$

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

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

The final equation for soil temperature is given by the following relationship:

$$T(z.t) = T_m + T_0 . exp\left(-\sqrt{\frac{\omega}{2\alpha}}.z\right).\cos\left(\omega t.\sqrt{\frac{\omega}{2\alpha}}.z\right) \quad \text{(II.4)}$$

Where the soil thermal diffusivity is given by: $\alpha = \frac{\lambda}{\rho \times C_P}$; $\omega = \frac{2\pi}{365}$

II.2.2 Modeling of the outlet temperature

The outlet temperature along the tube is influenced by both the tube diameter and airflow speed, as shown in the following relationship [20-23]:

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

The Nusselt number is determined according to the following Relationship

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

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

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

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

Can express the pipe's thermal resistance as:

$$R_{pipe} = \frac{1}{\lambda_{pipe}\times 2\times\pi} \times \ln(r_e \,|r_i) \ldots\ldots\ldots\ldots \text{(II.9)}$$

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

$$R_{conv} = \frac{1}{n\times h_{conv}\times 2\times\pi} \ldots\ldots\ldots\ldots \text{(II.10)}$$

Soil thermal resistance can be expressed as:

$$R_{soil} = \frac{1}{\lambda\times 2\times\pi} \times \ln(R_{(z.i)} \,|r_e) \ldots\ldots\ldots\ldots \text{(II.11)}$$

Then the total EAHE thermal conductivity is given by:

$$G_{Tot} = \frac{1}{(R_{conv}+R_{pipe}+R_{soil})} \ldots\ldots\ldots\ldots \text{(II.12)}$$

$$\frac{dT(x)}{T(z.t)-T(x)} = \frac{G_{Tot}}{\dot{m}\times Cp} \times dx \ldots\ldots\ldots\ldots \text{(II.13)}$$

II.2.3 Modeling of the Efficiency of the exchanger

The efficiency of the air-to-floor exchanger is defined as the ratio between the difference in air temperature (entering-leaving) and the temperature difference between the floor and that of the entering air given by the following expression[20-24]:

$$\varepsilon = \frac{[T_{in}-T_{out}]}{[T_{in}-T_{sol}]} \ldots\ldots\ldots\ldots \text{(II.14)}$$

The energy savings that can be achieved with the heat exchanger system are calculated by:

$$\boldsymbol{Energy\ saving}(\%) = [\mathbf{1} - \overline{\overline{\boldsymbol{T}}.\overline{\overline{\boldsymbol{E}}}.\overline{\boldsymbol{C}}}] \times \mathbf{100} \text{ \_\_\_\_ } \quad (II.22)$$

$$\overline{\boldsymbol{T}.\overline{\boldsymbol{E}}.\boldsymbol{C}}$$

Conclusions

In this chapter, thermal mathematical models based on the general heat transfer equation and the theory of thermal equilibrium have been presented. The aim of this chapter is to predict the temperature evolution in the soil and within the buried tube. Furthermore, a more professional and detailed rephrasing to delve deeper into defining the different parameters essential for evaluating the thermal efficiency of a geothermal heat exchanger was undertaken

RESULTATS ET DISCUSSIONS

II. Résultats et discussions

III.1. Introduction

In geothermal system configurations, the buried heat exchanger plays a crucial role, ensuring efficient utilization of geothermal energy when properly installed. This chapter aims to describe these buried heat exchangers and assess their effectiveness in various climates (dry and semi-dry). The rate of heat exchange extracted from the ground is used as an indicator to determine the efficiency of the buried exchangers. Additionally, various variables were studied, including airflow rate, inlet length and temperature, and depth of burial of the exchanger.

III.2. Thermal ground model

III.2.1 Soil temporary at different depths

These curves reveal a decrease in average temperatures with deeper soil layers, particularly pronounced in soils with low thermal diffusivity compared to other soil types.

Tableau III. 1: Thermal and physical properties of soil[20, 23, 29-34]

Type of soil	Density $kg.m^{-3}$	Thermal diffusivity $m^2 .h^{-1}$	Heat capacity $J.kg^{-1} .K^{-1}$
Clay	1500	0.00348	880
loam	1800	0.00223	1340
sand	1780	0.00135	1390
PVC pipe	1380	900	0.16
Air(300 K)	1.1774	1005.7	0.02624

The curves (**Figure III.1**, **Figure III.2**, **and Figure III.3**) depict the ground temperature at a certain depth, showing the average annual variations in soil temperature for three different types of soil studied (wet sand, clay sand, and clay sand silt). Based on these curves, we observe that the average temperatures decrease as we dig deeper into the soil. This variation is more pronounced in soils with low thermal diffusivity

(Tableau III. 2) compared to other soil types. The nature of the soil plays a crucial role in the burial and operation of the air-to-soil exchanger.

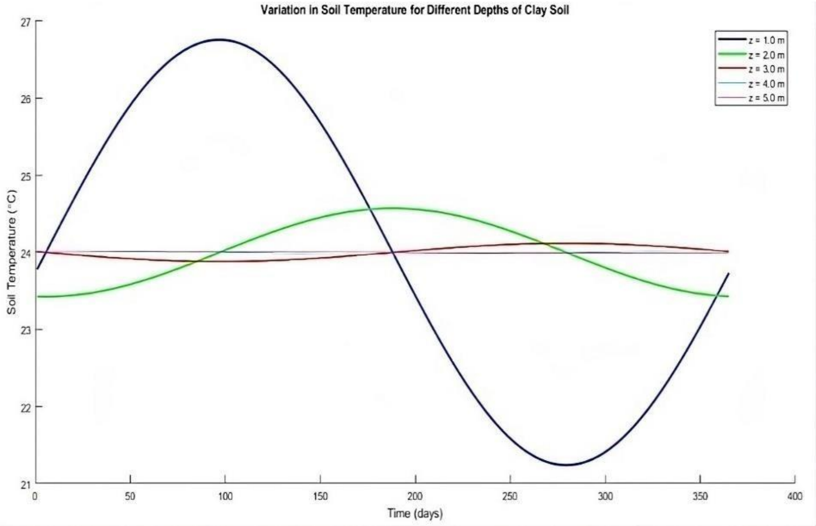


Figure III. 1: The soil temperature varies annually with depth in clay soil.

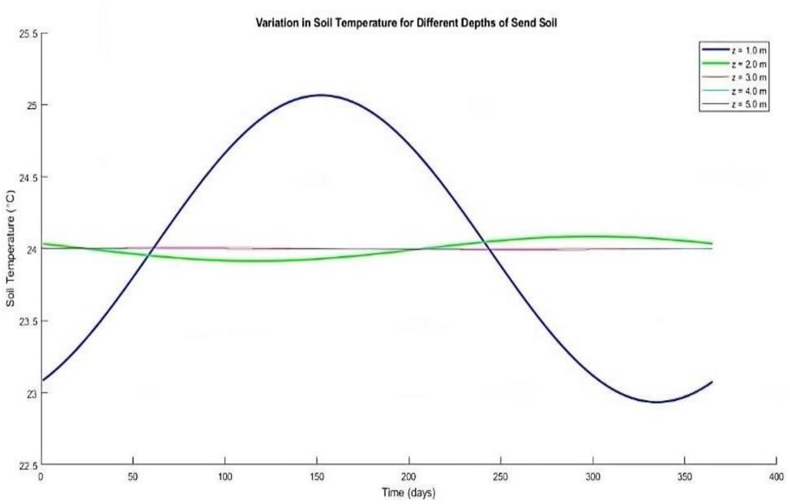


Figure III. 2: Yearly evolution of soil temperature as a function of depth for sandy ground.

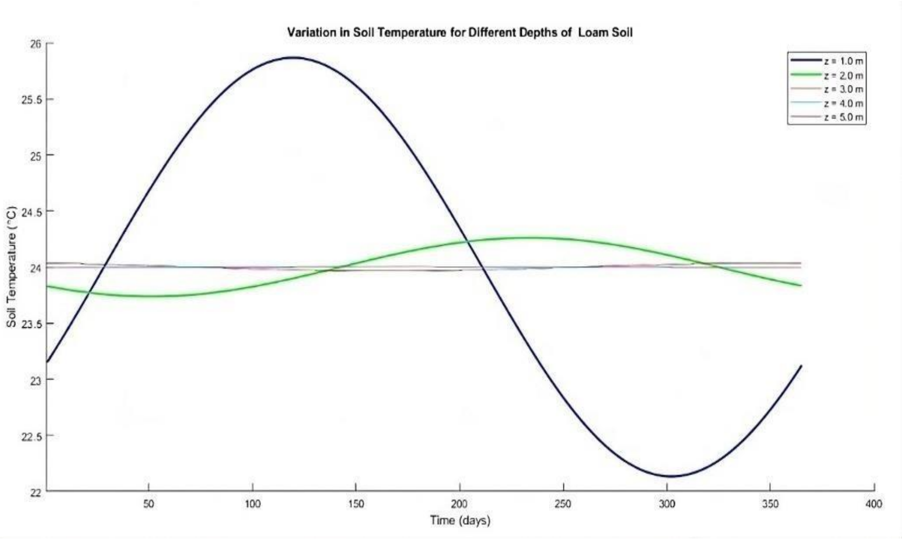


Figure III. 3: Hourly evolution of soil temperature as a function of depth for a clay-sandy loam ground

Figure III.4, The following trend illustrates the temperatures of three different types of soil (clay-sand silt, wet sand, clay) at a depth of three meters over the course of a full year. It is noted that there is a variation in soil temperature, as during the winter season, the maximum temperatures are recorded across all studied soil types, while this shift becomes minimal in the summer season. Additionally, it is observed that as the thermal diffusivity of the soil increases, its temperature rises, and vice versa.

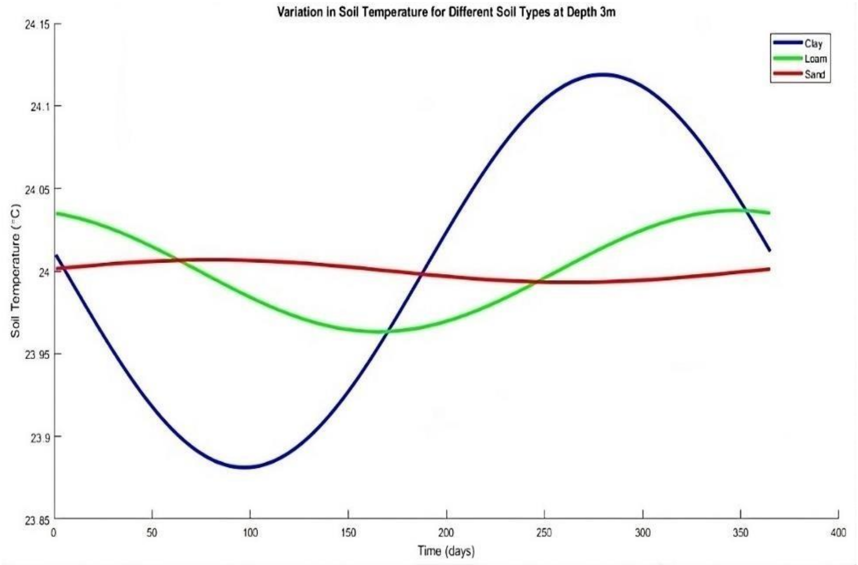


Figure III. 4: Yearly evolution of soil temperature for three types of soil at a depth of 3m

III.3. Evolution of the air outlet temperature

Table III.3 presents the parameters data used in the analysis of the air outlet temperature in the Earth-to-Air Heat Exchanger (EAHE) system. The parameters include the length, diameter, and depth of the pipe, as well as the slope of the pipe, soil temperature, and ambient temperature. These parameters are crucial for understanding the thermal performance and efficiency of the EAHE system

Tableau III. 3: parameters data[35]

parameter	**value**
Length of pipe (m)	45
Diameter of pipe (m)	0.160
Depth of pipe (m)	3
Slope of pipe (%)	2
Soil temperature (°C)	24.5
Ambient temperature(°C)	38

III.3.1 Effect of the inlet air temperature

Figure (III.5), The variations in air temperature exiting the heat exchanger as a function of length under the influence of the incoming temperature to the exchanger have been depicted. It has been observed that the outlet temperature decreases along the length of the tube. The incoming air temperature to the heat exchanger is crucial in transferring heat between air and soil, as the Earth-to-Air Heat Exchanger (EAHE) system heavily relies on the incoming air temperature to the heat exchanger. The same applies to the heat exchanger's capability to cool.

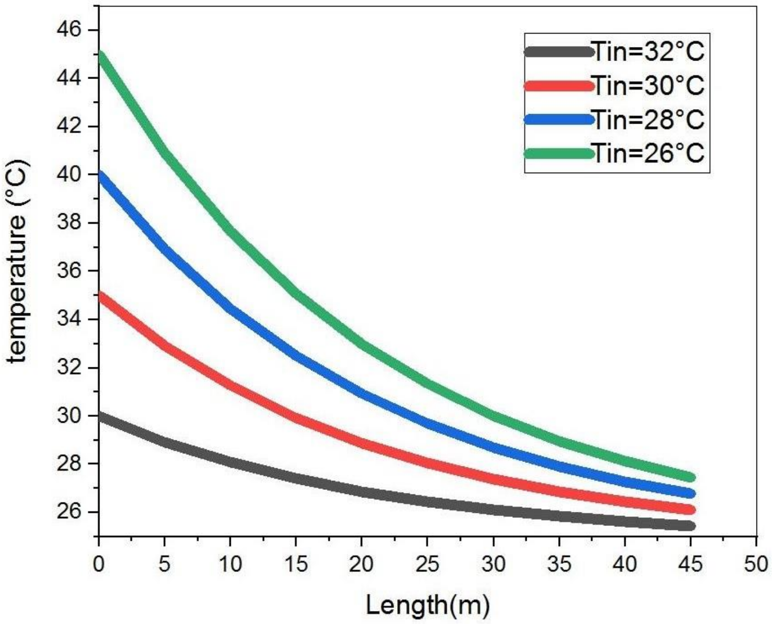


Figure III. 5: Effect Inlet air temperature

III.3.2 Effect of the Air velocity

Figure III.5 shows The variation in air temperature inside the Earth-to-Air Heat Exchanger (EAHE) occurs at different rates along the tube. Initially, we observe a rapid decrease in air temperature inside the EAHE from [40] to [25] degrees Celsius. Then, the air temperatureinside the heat exchanger stabilizes until it becomes constant between the soil and the air aftera length of [45] meters. Consequently, we conclude that the air velocity inside the heat exchanger pipes does not significantly affect the temperature of the air exiting the heat exchanger (T_out).

As for shape (Figure III.6) we observe that the efficiency of the heat exchanger changes and significantly increases up to a distance of [45] meters. However, after this length, we notice that this efficiency stabilizes. Therefore, we conclude that the air flow velocity affects the efficiency of the exchanger, but this effect remains constant after a certain distance of approximately [45] meters in this study

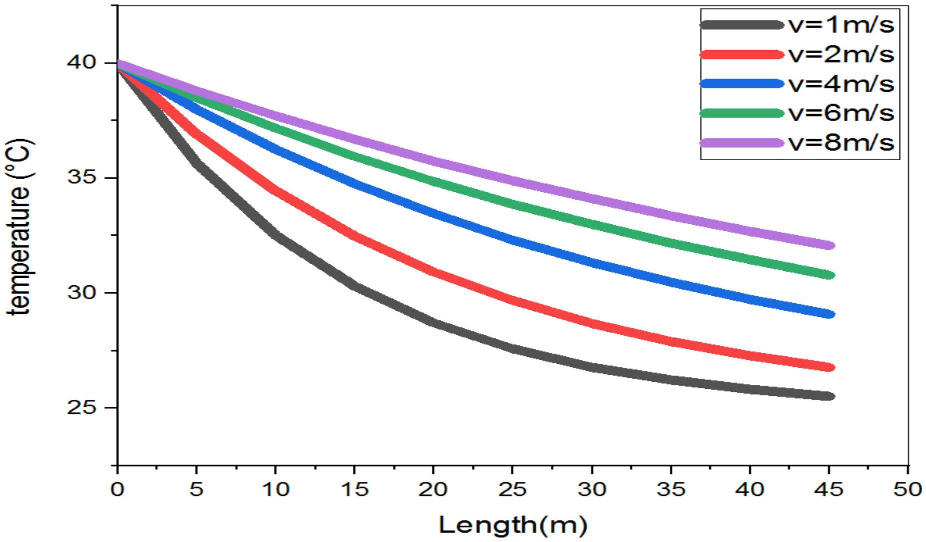


Figure III. 6: Effect of air velocity on temperature out of the air

General Conclusion

III. General Conclusion

According to the research we conducted on the variables that affect the efficiency and performance of heat exchangers, we found that several factors play a crucial role in determining their effectiveness. These factors include the materials used to make PVC pipes, pipe dimensions, burial depth, and soil physical properties. Our study highlights the complexity and interplay of these variables, each contributing uniquely to the overall performance of heat exchanger systems.

One of the significant findings is the impact of soil physical properties on the efficiency of heat exchangers. The thermal conductivity, moisture content, and density of the soil directly influence the heat transfer process. Soils with higher thermal conductivity and optimal moisture content enhance the heat exchange, thereby improving the system's efficiency. Conversely, dry or poorly conductive soils can diminish performance, underscoring the importance of site-specific soil analysis before installation.

Regarding the materials used for the pipes, our research indicates that while PVC is a commonly used material, its impact on performance is relatively negligible compared to other factors. This suggests that other considerations, such as cost and durability, might take precedence when selecting pipe materials.

The burial depth of the pipes (EAHE) emerged as a critical factor. We discovered that increasing the burial depth enhances the performance of the heat exchanger. Deeper burial allows for more stable temperatures and better insulation from surface temperature fluctuations, resulting in more efficient heat transfer. However, this must be balanced against the practical considerations of installation and maintenance.

Pipe dimensions also significantly influence performance. Contrary to what might be intuitively assumed, increasing the diameter of the heat exchanger pipes actually reduces the system's efficiency. Larger diameters decrease the surface area-to-volume ratio, leading to less effective heat exchange. On the other hand, pipe length plays a nuanced role; while increasing the length of buried pipes can enhance performance up to an optimal point, extending beyond this point can lead to diminishing returns and even a decrease in efficiency. This is likely due to increased friction losses and reduced temperature gradients over extended distances.

Airflow rate is another critical factor. Our findings indicate that higher airflow velocities reduce the heat exchanger's performance and efficiency. High velocities can lead to turbulent flow, which, while sometimes beneficial for heat transfer, in this context, seems to reduce the overall effectiveness of the system. To mitigate this, it is advisable to use a network of parallel pipes adequately spaced to prevent interaction effects due to high airflow. This configuration ensures that each pipe can efficiently benefit from the surrounding cooling or heating source without being affected by the airflow dynamics in adjacent pipes.

Based on the research conducted in our study, we can conclude the following:

- It has been confirmed that Air-to-Earth Heat Exchangers (EAHE) represent an effective solution for cooling and heating buildings in the studied area.
- It has been revealed that smaller-diameter pipes enhance heat exchange effectiveness more than larger-diameter pipes.
- The results indicate that increasing the length of the pipes enhances performance up to a certain point, but beyond this point, continued extension may lead to decreased efficiency;
- This study has demonstrated that increasing the airflow velocity reduces the efficiency of the heat exchanger.
- This work has shown that when using the heat exchanger, a significant cost reduction will be recorded;
- The maximum reduction in cooling load for a selected home using the EAHE system reached 15.54 % in July of the summer season, while in the winter season the maximum reduction in heating load was recorded at 15.70 % in January;
- With the EAHE system, the total required electricity for cooling and heating the selected home decreases, therefore, the saving in energy reached the maximum value of 11.5% at July in the summer and 14.2 % through January in the winter;
- he gross cost savings of energy consumed for 1 year for both summer and winter months reached (79$) with an expected payback period of approx- imately 9 years.

In conclusion, the performance of heat exchangers is influenced by a complex interplay of multiple factors. Optimal efficiency requires a careful balance and consideration of soil properties, pipe dimensions, burial depth, and airflow rates. By understanding and optimizing these variables, we can design more efficient and effective heat exchanger systems, tailored to specific environmental conditions and operational requirements.

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[35] BELOUL Samir, FERHAT Chihab, and KHOUAZEM Hatem, "ENERGETIC PERFORMANCE ANALYSIS OF GEOTHERMAL HEAT EXCHANGER UNDER SAHARAN CLIMATE," Master's Thesis, Mechanical engineering, ECHAHID HAMMA LAKHDAR UNIVERSITY OF EL-OUED, FACULTY OF TECHNOLOGY, 2020.

I. Résumé

In the region of South Algeria, where a harsh desert climate prevails, residents heavily rely on electricity for air conditioning during the summer. With continuous demographic growth and social and economic development, the demand for electricity is increasing, leading to a shortage in meeting this demand. From this perspective, the study offers environmentally friendly and cost-effective solutions by adopting ground thermal cooling technology. In this study, the Earth-Air Heat Exchanger (EAHE) air conditioning system was utilized, a simple and cost-effective technology that reduces energy consumption and environmental pollution levels. This technology is considered effective for heating and cooling buildings, where air is passed through pipes buried in the ground. These pipes utilize the stored heat in the ground to heat the air in winter and benefit from natural coolness to cool the air in summer, thus improving thermal comfort inside buildings at a low cost and in an environmentally friendly manner.

The study concludes that the EAHE system is effective for heating and cooling buildings in the studied area, resulting in an 11.4% reduction in energy costs. The total cost decreased from 93,181.96 Algerian dinars (692.32 US dollars) to 82,527.17 Algerian dinars (613.16 US dollars) with the EAHE system. The payback period for the system cost is estimated to be around 9 years. This renewable technology is effective for heating or cooling buildings, where air is passed through pipes buried a few meters underground. The stored heat in the ground is used to heat the air during winter, while natural coolness is used to cool the air during summer, contributing to improved thermal comfort inside buildings at a low cost and in an environmentally friendly manner.

ملخص :

في منطقة جنوب الجزائر، حيث يسود مناخ صحراوي قاسٍ، يعتمد السكان بشكل كبير على الكهرباء لتشغيل أجهزة التكييف خلال فصل الصيف. ومع النمو الديموغرافي المستمر والتطور الاجتماعي والاقتصادي، يزداد الطلب على الكهرباء، مما يؤدي إلى نقص في تلبية هذا الطلب. من هذا المنطلق، تقدم الدراسة حلولاً بيئية وفعالة من حيث التكلفة من خلال اعتماد تقنية التبريد الحراري الأرضي. تم في هذه الدراسة استخدام نظام تكييف الهواء بمبادل حراري هوائي أرضي (EAHE)، وهي تقنية بسيطة وفعالة من حيث التكلفة تعمل على تقليل استهلاك الطاقة ومستويات التلوث البيئي. تُعتبر هذه التقنية فعّالة في تدفئة وتبريد المباني، حيث يتم تمرير الهواء عبر أنابيب مدفونة في الأرض. تستفيد هذه الأنابيب من الحرارة المخزنة في الأرض لتدفئة الهواء في الشتاء، ومن البرودة الطبيعية لتبريد الهواء في الصيف، مما يحسن الراحة الحرارية داخل المباني بتكلفة منخفضة وبطريقة صديقة للبيئة.

تخلص الدراسة إلى فعالية نظام EAHE في تدفئة وتبريد المباني في المنطقة المدروسة، حيث أسفر استخدام النظام عن تخفيض تكاليف الطاقة بنسبة 11.4%. انخفضت التكلفة الإجمالية من 93,181.96 دينار جزائري (692.32 دولار أمريكي) إلى 82,527.17 دينار جزائري (613.16 دولار أمريكي) مع نظام EAHE. تُقدر فترة استرداد تكلفة النظام بحوالي 9 سنوات. تعد هذه التكنولوجيا المتجددة فعّالة لتدفئة أو تبريد المباني، حيث يتم تمرير الهواء عبر أنابيب مدفونة على بعد أمتار قليلة تحت الأرض. تُستخدم الحرارة المخزنة في الأرض لتدفئة الهواء خلال الشتاء، بينما تُستخدم البرودة الطبيعية لتبريد الهواء خلال الصيف، مما يساهم في تحسين الراحة الحرارية داخل المباني بتكلفة منخفضة وبطريقة صديقة للبيئة.