People's Democratic Republic Of Algeria
Ministry Of Higher Education and Scientific Research
University Of Echahid Hamma Lakhdar - El-Oued

Master’s Dissertation

In order to obtain a diploma of Master degree
Faculty of technology
Department: Mechanical Engineering
Specialty: Energetics

Entitled

Economic Evaluation of Geothermal Heat Exchanger in El Oued Region

Presented by:

1. ATALLAH Azzeddine
2. BEKKOUCHE Ahmed Amine

Publicly defended in: 27/05 /2025

Board of Examiners:

President	Mr.Atia Abdelmalek	Pr	El-Oued University
Examiner	Mrs.Horr Sabrina	MCB	El-Oued University
Supervisor	Mr.Zobiri oussama	MCB	El-Oued University

Academic Year 2025/2024

Abstract

In this work, it conducted an evaluation economic study of a ground air heat exchanger (GAHE) system. The purpose is to study the feasibility of connecting this exchange to buildings. The application was applied to a poultry house in ElOued region as a case study in order to reduce the consumption of polluting fossil energy used for thermal comfort of poultry. The cumulative cost of this experimental geothermal system over 30 years amounted to 2465560Algerian dinars (DZD), divided into maintenance of 60000 DZD and an initial investment in the first year of installing the system, which was estimated 1453000 DZD. It should not forget the electrical cost of the fans, which was 952560 DZD. On the other hand, it found that the carbon emissions resulting from the generation of electrical energy are estimated 130500.72 kgCO_2 and the temperature produced by this system is approximately 24.2°C.

Keywords **:** GAHE; Experimental; Geothermal energy; System cost; Economic.

الملخص

في هذا العمل، أجريت دراسة اقتصادية تقييمية لنظام مبادل حراري أرضي هوائي (GAHE). والغرض من ذلك هو دراسة جدوى ربط هذا المبادل بالمباني. وقد تم تطبيق التطبيق على حظيرة دواجن في منطقة الوادي كدراسة حالة من أجل تقليل استهلاك الطاقة الأحفورية الملوثة المستخدمة في الراحة الحرارية للدواجن. بلغت التكلفة التراكمية لهذا النظام التجريبي للطاقة الحرارية الأرضية على مدى 30 عامًا 2465560دينار جزائري (دج)، مقسمة إلى صيانة قدرها 60000 دج واستثمار أولي في السنة الأولى من تركيب النظام، والذي قُدّر بـ 1453000دج. ويجب ألا ننسى التكلفة الكهربائية للمراوح، والتي بلغت 952560دج. من ناحية أخرى، وجد أن انبعاثات الكربون الناتجة عن توليد الطاقة الكهربائية تُقدر بـ 130500.72 كغ من ثاني أكسيد الكربون، وأن درجة الحرارة التي ينتجها هذا النظام تبلغ حوالي 24.2 درجة مئوية.

الكلمات المفتاحية : GAHE؛ تجريبي؛ الطاقة الحرارية الأرضية؛ تكلفة النظام؛ اقتصادي.

Résumé :

Dans ce travail, une étude économique d'évaluation d'un système d'échangeur de chaleur géothermique (GAHE) a été réalisée. L'objectif est d'étudier la faisabilité du raccordement de cet échangeur aux bâtiments. L'application a été appliquée à un poulailler de la région de l'Oued, afin de réduire la consommation d'énergie fossile polluante utilisée pour le confort thermique des volailles. Le coût cumulé de ce système géothermique expérimental sur 30 ans s'est élevé à 2465560 dinars algériens (DA), répartis en 60 000 DA pour la maintenance et 1 453 000 DA pour l'investissement initial la première année d'installation. Il convient de noter le coût électrique des ventilateurs, estimé à 952 560 DA. Par ailleurs, les émissions de carbone résultant de la production d'énergie électrique sont estimées à 130 500 kgCO2, et la température produite par ce système est d'environ 24.2 °C.

Mots clés : GAHE; Expérimental ; Géothermie ; Coût du système ; Économique.

Acknowledgements

First, we thank **ALLAH**, our creator for giving us the strength to do this work.

We want to express our sincere gratitude to our supervisor **Dr. ZOBIRI Oussama (UEHL)**, for his excellent guidance, valuable advice, strong support, and continuous encouragement throughout the course of this research work at El Oued University. It has been a great pleasure and privilege to work under his supervision toward completion of this research.

Dedication

To our parents,

To our family,

To our friends.

Table of Contents

List of figures

List of tables

Nomenclature

EGS	Enhanced Geothermal System
WHO	World Health Organization
RH	Relative humidity,%
GAHE	Ground Air Heat Exchanger
EATHE	Earth Air Tunnel Heat Exchanger
GSHP	Ground Source Heat Pump
T_{sur}	Temperature Surface , ℃
T_m	Temperature Mean ,℃
Cs	Cost system , DZD
Ce	Cost Electricity, DZD
Cm	Cost Maintenance , DZD
EAHE	Earth-Air heat Exchanger
HVAC	Heating, Ventilation, and Air Conditioning
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
GHE , GHX	Geothermal Heat Exchanger
TPH	Traditional Poultry House
CO_2	Dioxide Carbon
DZD	Algerian Dinars
PVC	PolyVinyl Chloride
N	Number of years

General introduction

One of the key renewable energy kinds is geothermal energy, which is environmentally beneficial, green, dependable, and sustainable. It comes from the creation of the planet and is mostly the heat produced and kept beneath the Earth's crust. The geothermal energy, though, is typically the portion of the Earth's heat that may be used for a variety of commercial applications, including electricity production, space heating and cooling, and aquaculture, as well as for household and therapeutic uses like swimming and bathing[1, 2]. All of the methods employed to exploit the potential of geothermal energy work to make use of the thermal energy contained in the planet. Low and high enthalpy resources are utilized using, respectively, shallow and deep geothermal techniques [3, 4].

Renewable energies are clean and compatible with The potential of geothermal energy can be harnessed through a number of techniques, all of which attempt to utilize the thermal energy stored within the earth Geothermal energy has traditionally been used to refresh people in our Sahara region, where they construct their houses underground to be comfortable during the summer. The primary goal in desert climates is to achieve thermal comfort inside a building while using as little energy as possible. Desert climates are hot and dry, and similar conditions may be found in several places around the globe. South Algeria is one such region, where the average temperature is near nature and there are countless natural geothermal springs. With the development of energy costs, geothermal energy, like other renewable energy sources, must now be examined with renewed interest, particularly in the area of building heating and cooling, where this potential is not currently used to a large extent. Practical engineering has made use of geothermal energy as an environmentally beneficial energy source with a wide range of uses, including space heating and cooling, hot water supply, and applications in the agricultural sector. Ground source heat pump systems are most well-known for their use in space heating and cooling in homes and businesses [5].

The El Oued area of southeast Algeria has a unique geology and climate[6], making it a potential location for geothermal energy development. The utilization of geothermal heat exchanger systems represents an interesting technological opportunity to be evaluated in the El Oued area due to its Saharan climate, which is marked by large temperature variations between day and night and a strong need for air conditioning and heating. This study is a component of this dynamic and seeks to evaluate the economic feasibility of installing a geothermal heat exchanger in the El Oued region. The research will cover the system's technical details, investment and maintenance expenses, and projected economic benefits in the near, medium, and long run. The goal is to assess the viability of such a facility and its potential as a sustainable energy option that meets regional needs.

Chapter I: Geothermal Energy and Thermal Comfort

I.1. Introduction

Geothermal energy as a source of renewable energy, its use in the production of heat and electricity, and the main applications and technologies. Geothermal energy is the thermal energy stored underground, including any contained fluid, which is available for extraction and conversion into energy products. Electricity generation, which today produces 73.7 TWh (12.7 GW of capacity) worldwide, usually requires geothermal temperatures of over 100 °C. For heating, geothermal resources that span a wider range of temperatures can be used in various heat applications such as; space and district (and cooling, with the appropriate technology), spas and swimming pools, greenhouses and soil, aquaculture ponds, industrial processes and snow melting. The geothermal heat produced worldwide is 164.6 TWh, with a capacity of 70.9 GW. Geothermal resources are immune from weather and seasonal variations, and can produce a base-load (continuously) or adapt to the energy demand, providing a flexible and “smart” renewable energy source. To guarantee a sustainable use of geothermal energy, the consumption rate should not exceed the generation rate, so that the heat removed from the resource is replaced within a similar time scale, and geothermal plants typically produce energy below a certain level. In addition, any impact on the environment should be controlled, mitigated and managed. Any non-sustainable use of geothermal technologies can create a misperception of geothermal energy and social resistance to geothermal development[7].

I .1 Trends on direct heat applications of geothermal energy

Geothermal energy has significant direct applications in various countries worldwide. Notable examples include space heating in Iceland, commercial processing in Australia, greenhouse heating in Austria, and traditional bathing practices in Japan. This direct usage, also referred to as non-electrical applications, covers the full spectrum of geothermal temperatures. Most direct uses rely on existing technology and straightforward engineering[8].

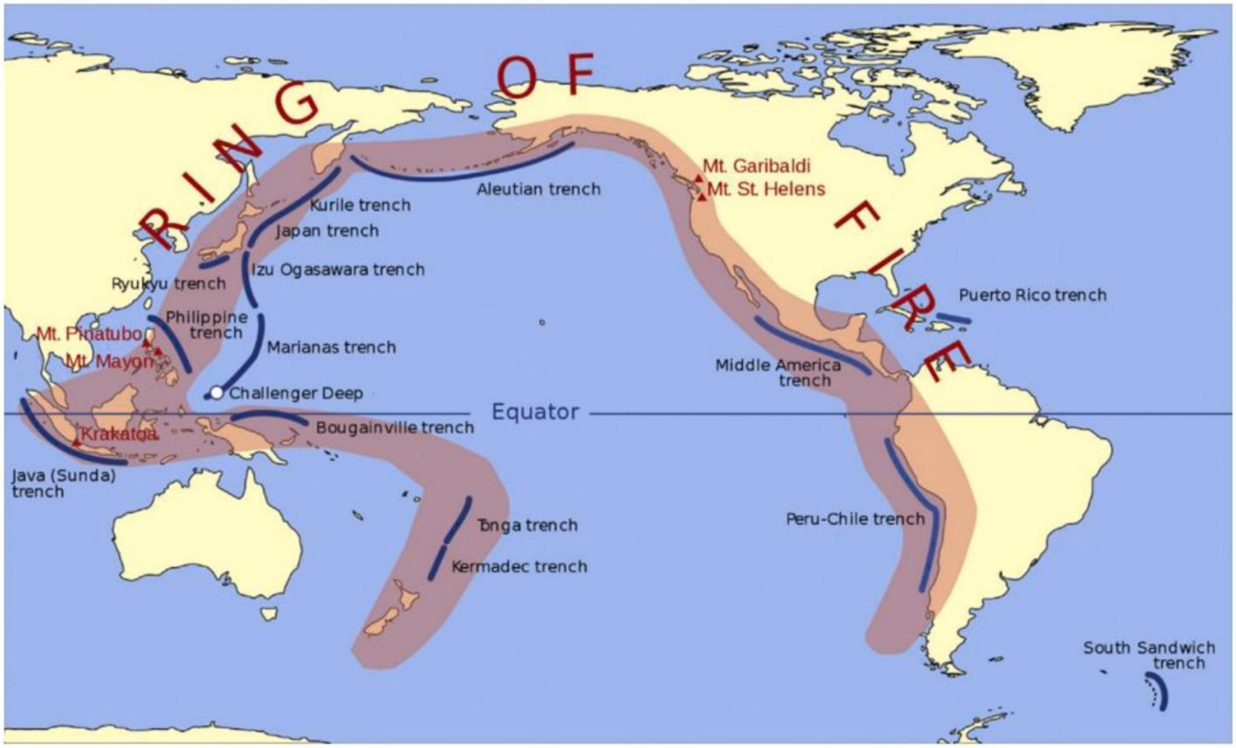


Fig I.1 The Ring of Fire[9]

The most common method of harnessing geothermal energy involves drilling wells into underground reservoirs of hot water and steam, then pumping the heated water or steam to the surface for use in heating and energy generation for buildings such as homes and offices. For instance, Reykjavik, the capital of Iceland, with a population of approximately 120,000, uses a district heating system that transports hot water from a spring located 25 kilometers away. This hot water is utilized not only for heating but also for household tap water.

The utilization of geothermal resources has been proven to be technically viable, economically feasible, and environmentally sustainable worldwide. The primary applications of direct geothermal energy include bathing and swimming (45%), heating systems (38%, with 13% supplied by geothermal heat pumps), fish farming (9%), greenhouse heating (10%), and industrial processes (5%). The cost of production per kWh varies but is generally less than $4/kWh.

According to reports from the World Geothermal Congress 2015, the number of countries utilizing direct geothermal energy increased to 82, up from 78 in 2010, 71 in 2005, 58 in 2000, and 28 in 1995. The total thermal energy consumption reached 523,850 TJ/year, reflecting a 57% increase since 2005 and a compound annual growth rate of 9.2%.

Due to advancements in direct-use geothermal technology, the global installed capacity reached 91.33 GW, growing at an annual rate of 8.56% with a utilization factor of 0.263. According to Lund and Boyd, the total thermal energy usage worldwide was 577,736 TJ/year, increasing at a compound annual rate of 6.6%. This energy use is classified into nine categories, including geothermal heat pumps, greenhouse and pond heating, industrial applications, snow melting, refrigeration, and more.

The World Geothermal Congress 2020 reported an additional 26 countries utilizing geothermal energy, bringing the total to 108 countries, compared to 82 in 2015, 78 in 2010, 72 in 2005, 58 in 2000, and 28 in 1995. By the end of 2019, the estimated installed capacity for direct geothermal usage reached 107,727 MWt, marking a 52% increase from 2015, with a compound annual growth rate of 8.73%. Additionally, thermal energy consumption rose by 72.3% since 2015, reaching 1,020,887 TJ/year, with an annual growth rate of 11.5%.

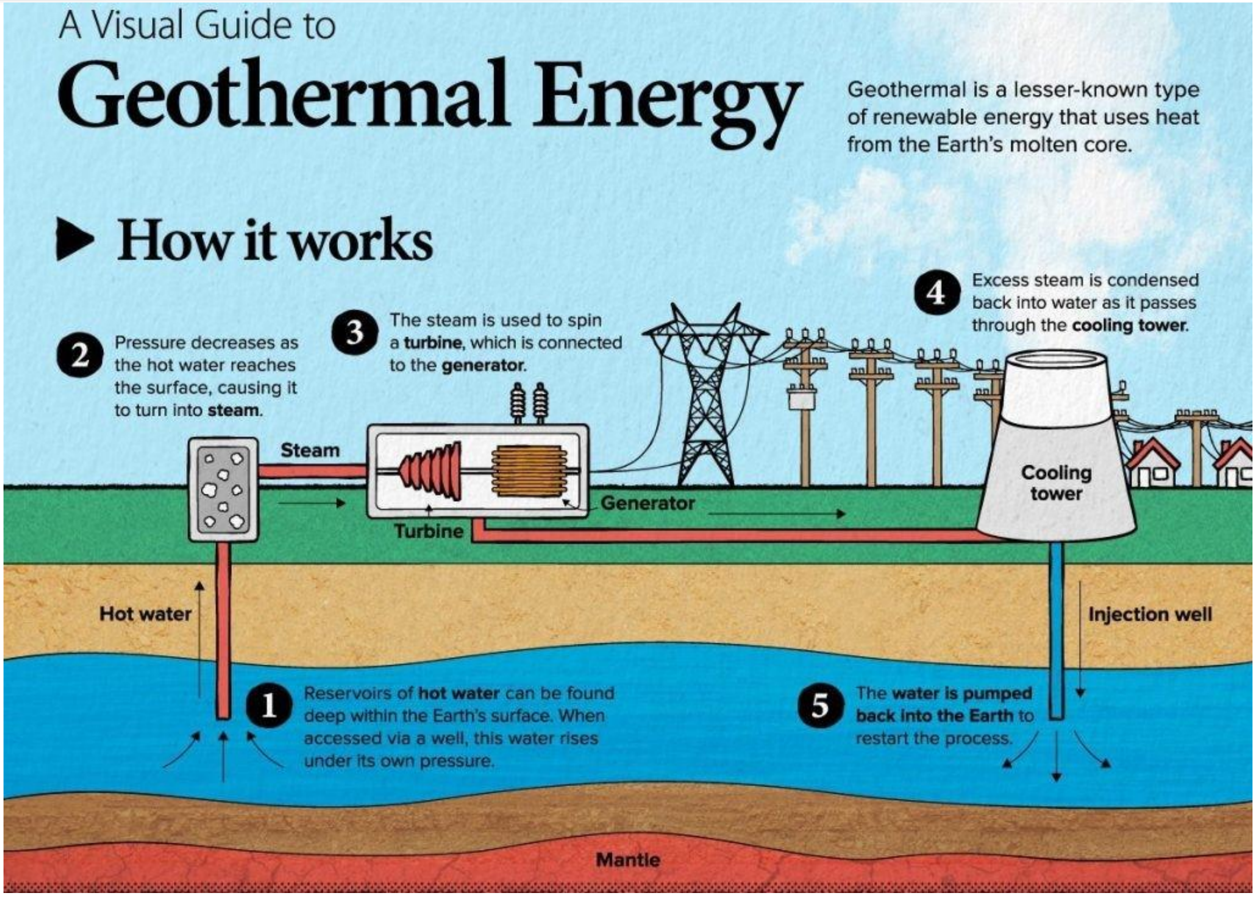
I.1.1 Trends on geothermal energy in power plant technology

Between 10% and 17% of electricity is generated using geothermal steam, which is approximately three times less efficient than nuclear or fossil fuel power plants. This lower efficiency is primarily due to the fact that the steam produced in geothermal facilities often has a temperature below 250°C. The total installed geothermal power capacity is 7,974 MW, accounting for about 3% of global energy demand. Since 1965, geothermal power generation capacity has grown at an average annual rate of approximately 250 MW.

To efficiently generate electricity from geothermal energy, it is essential to convert geothermal heat into electrical power using surface-based generation systems designed for effective thermal-to-electric energy conversion. Researchers have developed five primary geothermal power plant configurations, which can be broadly categorized into two groups: steam cycles for high-enthalpy resources and binary cycles for lower-enthalpy resources. These configurations include dry steam, single-flash, double-flash, and advanced geothermal energy conversion systems.

Globally, the minimum required geothermal electricity production should reach 1 TW, but only 32% of the world's geothermal resources are suitable for energy production. The extraction of geothermal energy depends on the condition of the resource and the technology used. Dry steam systems are employed at higher temperatures when the geothermal fluid exists as superheated vapor. Currently, dry steam plants account for about 23% of global geothermal capacity, with 63 operational plants producing a total of 2,863 MW. Dry steam power plants are the cheapest and most efficient among all geothermal energy systems.

Single-flash plants contribute approximately 42% of the world's geothermal power generation capacity, while double-flash plants account for 19%, making flash steam plants the most widely used geothermal power plants globally. Additionally, binary cycle power plants contribute 14% of the total geothermal capacity, with 286 operational plants generating 1,790 MW of electricity. However, the second law of thermodynamics limits the amount of energy that can be converted into electricity. The efficiency of geothermal power plants depends on optimal plant design and the performance of their various components[10].



Geothermal is a lesser-known type of renewable energy that uses heat from the Earth's molten core.

1 Reservoirs of **hot water** can be found deep within the Earth's surface. When accessed via a well, this water rises under its own pressure.

2 Pressure decreases as the hot water reaches the surface, causing it to turn into **steam**.

3 The steam is used to spin a **turbine**, which is connected to the **generator**.

4 Excess steam is condensed back into water as it passes through the **cooling tower**.

5 The **water is pumped back into the Earth** to restart the process.

Fig I.2 Geothermal energy trends in power plant technology

I.1.2 Trends on enhanced geothermal systems (EGS).

The Enhanced Geothermal System, known as EGS, is a cutting-edge method that taps into energy found in hot dry rock, or HDR. The idea of using HDR as a clean and renewable source of energy for generating electricity is quite new. EGS differs from hydro-geothermal systems because it can obtain energy from dry rock layers even if there is little or no natural water present.

This method functions by boosting the hydraulic effectiveness of a geothermal reservoir in a man-made way. This allows a fluid to be pumped in, heated by the surrounding rock, and then sent to a power generation facility or a combined heat and power site. Plants that utilize EGS are more effective compared to traditional geothermal energy systems and can play an essential role in providing low-temperature thermal energy[11].

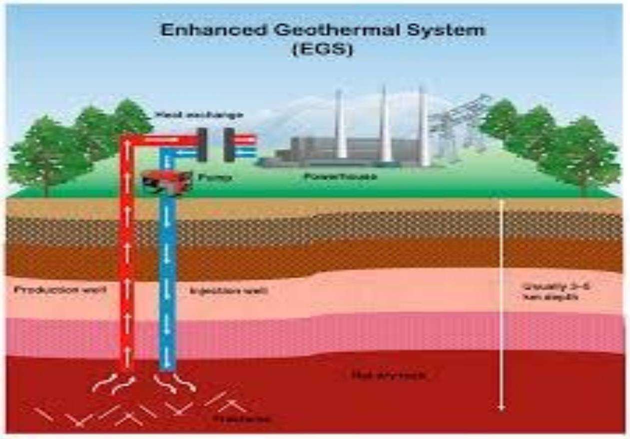


Fig I.3 Enhanced geothermal systems (EGS).

I.2 Exploration for geothermal resource.

Before starting extraction, it is essential to explore possible geothermal reservoirs. Geothermal resources appear in different types, but an effective conventional geothermal system depends on three main components: heat, permeability, and water. The core of the Earth constantly sends heat outward, usually remaining below the surface, which warms surrounding rocks and water to temperatures that can reach several hundred degrees Celsius. In some situations, this heat breaks through as lava or magma. When hot water or steam gets trapped in permeable and porous rock situated under an impermeable layer, a geothermal aquifer can be created. While geothermal water can occasionally surface as hot springs, most of it stays underground, confined in fractures and permeable rock structures. This natural storage of heated water is called a geothermal reservoir.

At present, the extraction of geothermal energy is confined to fairly shallow levels due to technical and financial limitations. So far, drills have reached depths of less than five kilometers in geothermal reservoirs. Like any natural resource, geothermal exploration demands a well-organized approach. After identifying a geothermal area, scientists must use different investigative methods to find potential geothermal sites and determine the best targets for fluid extraction. Moreover, aspects like temperature, reservoir capacity, and permeability at various depths need to be evaluated. It is also vital to estimate the chemical makeup of the geothermal fluid intended for extraction. There are several exploration techniques available to gather this essential information[12].

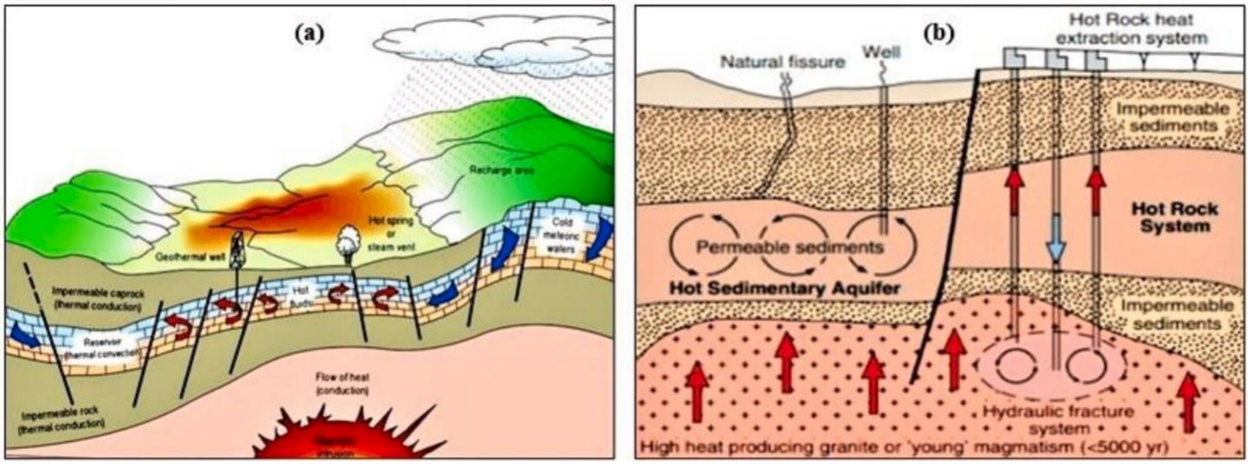


Fig I.4 **. (a)** Schematic representation of an ideal geothermal system and **(b)** Hot rock and hot sedimentary aquifer system[13].

I.3 Extraction of geothermal energy.

Before proceeding with extraction, exploring geothermal reservoirs is a crucial step in identifying suitable locations. Optimal conventional geothermal systems rely on three key elements: heat, permeability, and water. The Earth's core continuously radiates heat outward, which typically remains trapped beneath the crust, heating surrounding rocks and water to temperatures that can reach several hundred degrees Celsius. In some cases, this heat escapes to the surface in the form of lava or magma. When hot water or steam is confined within porous and permeable rock beneath an impermeable layer, a **geothermal reservoir** is formed. While some geothermal water may emerge as hot springs, the majority remains trapped underground within fractures and permeable rock formations.

Currently, geothermal energy extraction is limited to relatively shallow depths due to technical and economic challenges, with drilling operations not exceeding five kilometers. Like any natural resource, geothermal energy exploration requires a precise and well-structured methodology. Once a geothermal zone is identified, various research techniques are applied to locate promising extraction sites and select optimal targets for fluid production. This process involves evaluating key factors such as temperature, reservoir capacity, and rock permeability at different depths, along with analyzing the chemical composition of the extracted geothermal fluid. Several exploration methods are available to gather this critical data, ensuring efficient and sustainable energy extraction[14, 15].

I.4 Utilisation of Geothermal Energy

I.4.1 Chemical Pollution

The environmental impact of geothermal energy utilization is primarily associated with chemical pollution caused by airborne and waterborne contaminants. Geothermal waters typically contain significantly higher salt concentrations than regular groundwater, along with various elements at levels exceeding permissible limits for domestic use, irrigation, livestock watering, industrial applications, and aquatic life. The most concerning elements include arsenic, boron, hydrogen sulfide, and high overall salinity. Additionally, trace elements such as arsenic, mercury, lead, manganese, and zinc can be found in elevated concentrations, particularly in saline fluids. Dilute high-temperature geothermal water may also contain high aluminum concentrations, which can far exceed the limits allowed for domestic use and pose a threat to aquatic ecosystems.

Geothermal steam contains various gases and volatile compounds, including carbon dioxide (CO2), hydrogen (H2), hydrogen sulfide (H2S), methane (CH4), atmospheric gases, mercury (Hg), and occasionally boron (B). The most prevalent gases are CO2, H2S, and H2. These gases can originate from the magma heat source, the surrounding rocks that interact with geothermal fluids, or chemical reactions such as methane formation through CO2 reduction. Greenhouse gases like CO2 and CH4 are present in highly variable concentrations, influenced by equilibrium processes or the heat source itself. High methane and boron levels are particularly common in high-temperature systems associated with marine sediments, such as the Ngawha geothermal field in New Zealand. Some volcanic geothermal systems, such as those in Kenya's Eastern Rift Valley, contain steam with up to 10% CO2 concentration.

Among geothermal steam gases, hydrogen sulfide (H2S) poses the most significant environmental concern due to its high toxicity, corrosive nature, and pungent odor. To mitigate atmospheric pollution, H2S is commonly removed from non-condensable gases extracted from turbine condensers. Several removal methods are available, with the most widely used involving the oxidation of H2S into either elemental sulfur or sulfate, significantly reducing its harmful emissions into the environment.

I.4.2 Other factors

I.4.2.1 Induced Seismicity

Seismic instability may occur in geologically active areas due to geothermal energy utilization, particularly during fluid reinjection into geothermal reservoirs. This reinjection process can generate pressure changes in underground formations, potentially triggering seismic activity. However, this risk can be minimized by maintaining reinjection pressures at the lowest possible levels to avoid excessive stress on subsurface rock layers.

I.4.2.2 Noise Pollution

Noise pollution is another environmental issue linked to geothermal energy projects. It can cause disturbances or health concerns depending on the noise intensity. According to the World Health Organization (WHO), noise levels should not exceed 55 dB in outdoor residential areas and 70 dB in industrial areas.

Geothermal energy operations can generate noise pollution during both drilling activities and plant operations, with noise levels rarely exceeding 90 dB. However, such noise can be disruptive for nearby residents and may also affect tourism. In Kenya, anecdotal evidence suggests that drilling noise has scared away wildlife, while pipelines and pylons have interfered with the migration of certain animal species.

To mitigate noise pollution, appropriate noise control measures should be implemented, especially in areas near human settlements. The use of silencers or noise mufflers can reduce noise levels to below 65 dB, in line with the regulations set by the US Geological Survey[16].

I.5 Thermal Comfort

Thermal comfort is a crucial aspect of environmental quality that significantly impacts human well-being, productivity, and overall health. It refers to the state of mind in which an individual feels satisfied with the surrounding thermal environment, without experiencing sensations of being too hot or too cold. Achieving thermal comfort is essential in various settings, including residential buildings, workplaces, and public spaces, as it directly affects human performance and quality of life.

Thermal comfort is influenced by a combination of environmental factors such as air temperature, humidity, air velocity, and radiant temperature, along with personal factors including clothing insulation and metabolic rate. The balance between these factors plays a vital role in determining whether an individual perceives the thermal environment as comfortable or uncomfortable.

Designing indoor environments to provide optimal thermal comfort requires understanding human thermal perception, climate conditions, and energy efficiency strategies. Therefore, the assessment and management of thermal comfort are essential in architectural design, heating, ventilation, and air conditioning (HVAC) systems, and sustainable building practices.

With the growing emphasis on energy conservation and green building technologies, achieving thermal comfort while minimizing energy consumption has become a key challenge in modern building design. Various standards, such as those established by ASHRAE and ISO, provide guidelines to ensure thermal comfort while promoting energy-efficient solutions[17].

I.6 Thermal comfort is traditionally linked to 6 parameters.

1.Metabolism, which is the production of heat internal to the human body allowing it to be maintained around 36.7°C. A working metabolism corresponding to a particular activity is added to the basic metabolism of the body at rest.

2. Clothing, which represents thermal resistance to heat exchange between the surface of the skin and the environment.

3.The ambient air temperature Ta.

4.The average wall temperature Tp.

5. Relative humidity of the air (RH), which is the ratio expressed as a percentage between the quantity of water contained in the air at temperature ta and the maximum quantity of water contained at the same temperature

6. Air speed, which influences heat exchange by convection. In buildings, air speeds generally do not exceed 0.2 m/s

I.6.1 Comfort and temperature.

Under normal conditions, the human body maintains its temperature at approximately 36.7°C, which is consistently higher than the surrounding ambient temperature. To ensure thermal comfort, a balance must be established between the heat generated by the body and the heat lost to the environment, allowing the individual to feel comfortable without experiencing excessive heat or cold [18].

Fig I.5 Analysis of the relationship between Air Temperature and Predicted Percentage of Dissatisfied (PPD) According to activity level

The figure above considers the feeling of thermal comfort expressed by the subjects themselves. These are predictable percentages of dissatisfaction (PPD), expressed on the vertical axis, for people resting in a seated position (those who take a nap at the office, for example!), or for people doing light work (office work).

I.6.2 Comfort and humidity

Humidity plays a crucial role in determining thermal comfort, as it directly affects the body's ability to regulate temperature through perspiration. It refers to the amount of water vapor present in the air, typically expressed as relative humidity (RH) in percentage. Maintaining an appropriate level of humidity is essential to ensure a comfortable indoor environment.

High humidity levels can make the surrounding air feel warmer than the actual temperature, as it reduces the evaporation rate of sweat from the skin, preventing the body from cooling down effectively. This sensation can cause discomfort, fatigue, and difficulty in breathing. Conversely, low humidity accelerates sweat evaporation, which may lead to excessive cooling, dry skin, eye irritation, and respiratory problems.

According to ASHRAE standards, the recommended indoor relative humidity for optimal thermal comfort ranges between 40% and 60%. Proper humidity control, combined with adequate ventilation and temperature regulation, contributes significantly to enhancing thermal comfort and promoting overall well-being in indoor environments[19].

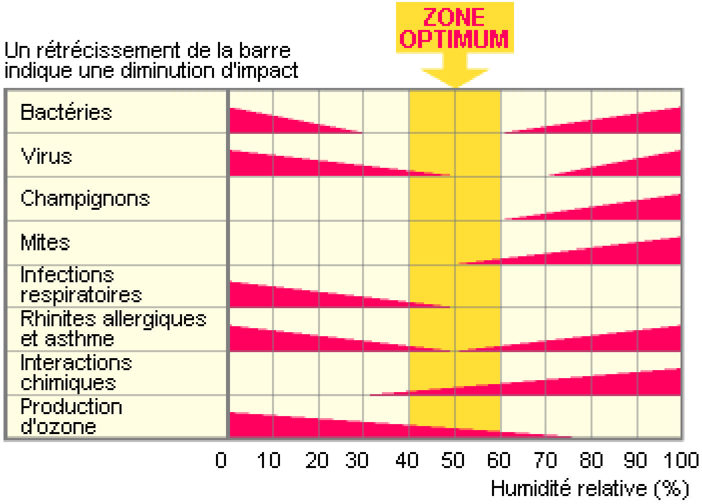


Fig I.6 Impact of Relative Humidity on the Proliferation of Biological Agents and Chemical Interactions in Indoor Environments

I.6.3 Comfort and Air velocity

Air velocity is a critical parameter that influences thermal comfort, as it affects the rate of heat exchange between the human body and the surrounding environment. Air movement plays a vital role in enhancing comfort by promoting heat dissipation through convection and evaporation.A moderate airflow helps the body lose heat more efficiently, especially in warm environments, by accelerating sweat evaporation and providing a cooling sensation. However, excessive air velocity can create discomfort, particularly in cold environments, as it increases heat loss and makes the person feel colder.

According to ASHRAE standards, the acceptable air velocity for indoor environments typically ranges between 0.1 m/s and 0.3 m/s to ensure optimal thermal comfort. The ideal air speed varies depending on factors such as temperature, humidity, and individual preferences. Proper air distribution systems and adjustable ventilation contribute to maintaining the right balance, enhancing both comfort and air quality in indoor spaces[20].

I.6.4 Comfort, Activity, and Clothing

Thermal comfort is influenced by several personal factors, including physical activity levels and clothing insulation. These elements play a crucial role in determining how the human body perceives and regulates temperature in different environments.

- Activity Level (Metabolic Rate) : The amount of heat produced by the body depends on the intensity of physical activity. Higher activity levels generate more internal heat, making individuals feel warmer. The metabolic rate is measured in metabolic units (MET), where 1 MET represents the heat produced by a seated person at rest (approximately 58 W/m^2). The greater the activity, the higher the heat generated, requiring cooler environments to maintain comfort

- Clothing Insulation : Clothing acts as a thermal barrier between the body and the surrounding environment. The insulation value of clothing is measured in clo units, where 1 clo represents the insulation provided by typical indoor clothing. Lighter clothing improves heat dissipation, making it suitable for warm environments, while heavier clothing helps retain body heat in colder conditions. Proper clothing selection is essential to maintain thermal comfort under varying temperatures.

The interaction between activity level and clothing insulation significantly affects an individual's perception of comfort. For example, a person performing intense physical activity requires lighter clothing and a cooler environment to maintain balance, while someone at rest needs warmer clothing to prevent heat loss Achieving thermal comfort requires considering both environmental conditions and personal factors to ensure the best possible balance for human well-being[21].

I.7. Conclusion

Geothermal energy is among the most eco-friendly and sustainable sources of renewable energy. It has great potential to satisfy the increasing global energy needs while reducing environmental harm. This energy source can provide both electricity and direct heating, which makes it adaptable for different areas such as homes, businesses, and industries. A key use of geothermal energy is in improving comfort levels in buildings via effective heating, cooling, and climate control technologies.

Geothermal systems harness the heat from beneath the Earth's surface to maintain steady indoor temperatures with a low impact on the environment. Geothermal heat pumps are well-known for their capability to manage indoor climates by moving heat from the ground into buildings in the winter and extracting excess heat during the summer, ensuring comfort throughout the year. Compared to traditional heating and cooling methods, geothermal systems require less energy and emit fewer greenhouse gases, thereby being both affordable and environmentally friendly.

Furthermore, geothermal energy is vital for keeping key comfort factors like air temperature, humidity, and airflow in balance. These systems can maintain consistent temperatures that meet human comfort standards while also improving air quality. Additionally, the low noise produced by geothermal energy systems contributes positively to indoor settings, especially in homes and city environments.

Despite the many benefits, the broader use of geothermal energy still encounters some hurdles such as high upfront installation costs, geographical restrictions, and the need for better technologies to effectively tap into deep geothermal resources. Nevertheless, ongoing advancements in technology and an increasing emphasis on environmental issues are likely to lead to more development and investment in geothermal energy solutions.

So, geothermal energy is a viable option for enhancing comfort while tackling global energy and environmental problems. Its ability to provide dependable, clean, and efficient heating and cooling not only enhances living standards but also aids in lowering the carbon footprint of buildings. As society shifts towards sustainable energy options, incorporating geothermal systems into new infrastructure will be crucial for creating energy-efficient and comfortable habitats for future generations.

Chapter II: Integration of Geothermal energy with heat exchangers

II.1 Introduction

Ground temperature measurements show that, below a certain depth, the temperature remains relatively stable throughout the year. This stability is due to the soil's high thermal inertia, which reduces surface temperature fluctuations with depth.

Additionally, a time lag exists between surface temperature changes and those deeper in the ground. As a result, at sufficient depths, the ground remains warmer than the air in winter and cooler than the air in summer. The temperature variation at different depths during both summer (August) and winter (January) as data from the North African region have shown. Below five meters This temperature difference between the ground and outside air can be utilized for energy efficiency. A ground heat exchanger can preheat the air in winter and precool it in summer.Furthermore, heat pumps, which are more efficient than traditional heating systems, can extract heat from the ground in winter and transfer it into buildings, or remove heat from the building in summer and store it in the ground. Ground source heat pumps are becoming increasingly popular, with over 550000 units installed globally, 80% of which are for residential use, and more than 66000 units being installed each year[22] .

II.2 Definition:

Ground Air Heat Exchangers (GAHE) are a technique designed to promote energy efficiency. GAHE is an innovative method of space heating and cooling that utilizes heat from the earth's subsurface. The following subsections offer a clear summary of previous research on GAHE. The review highlights the results related to thermal performance and provides an in-depth discussion of both analytical and experimental studies on various GAHE configurations[23] .

II.3 Working principle of GAHE

The Ground-Air Heat Exchanger (GAHE) is a passive underground system that provides cooling in summer and heating in winter. It uses air to transfer heat, with the soil acting as a heat source or sink. In a typical GAHE, external air flows through buried pipes and exchanges heat with the surrounding ground. A blower forces ambient air through these pipes, where it either gains or loses heat based on the soil temperature. The conditioned air is then used for cooling or heating. The system's performance improves with the depth of the pipes, although deeper installations increase initial costs. It is recommended that horizontal ground heat exchanger pipes be buried 3-4 meters underground. The system's summer cooling operation is illustrated in Figure I.8 [24]

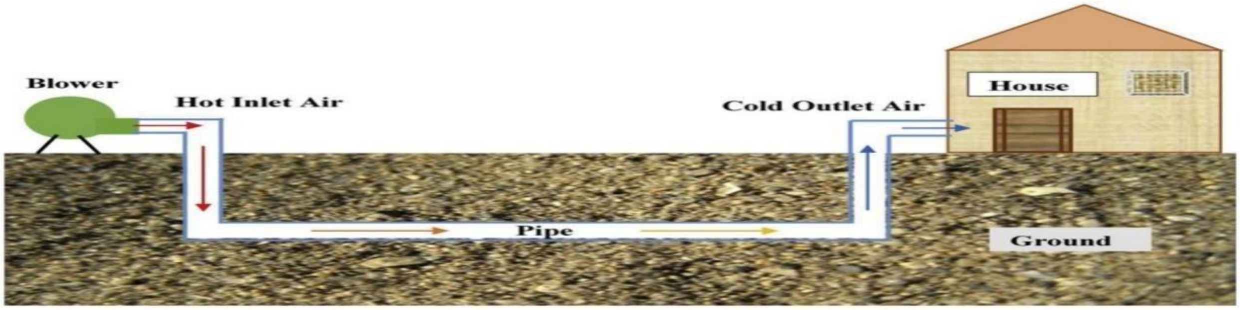


Fig II.1- Working principle of GAHE system for summer cooling[25] .

II.4 Types of ground heat exchangers

There are two main types of ground heat exchangers: open and closed systems. In an open system, the ground directly heats or cools a medium used for space heating or cooling. In contrast, a closed system uses a heat carrier medium to indirectly transfer heat through the ground. The heat exchanger loop is typically made from durable materials like high-density polyethylene, known for its heat-fused joints and a lifespan of up to 50 years. Another type uses copper piping placed underground, where refrigerant circulates to transfer heat directly to the earth. The loop's length depends on factors such as configuration, heating and cooling demands, soil conditions, and climate.

II.4.1 Open systems

In open systems, the ambient air flows through tubes buried underground for preheating or pre-cooling. Afterward, the air is further heated or cooled by a traditional air conditioning unit before entering the building (Fig II. 2).

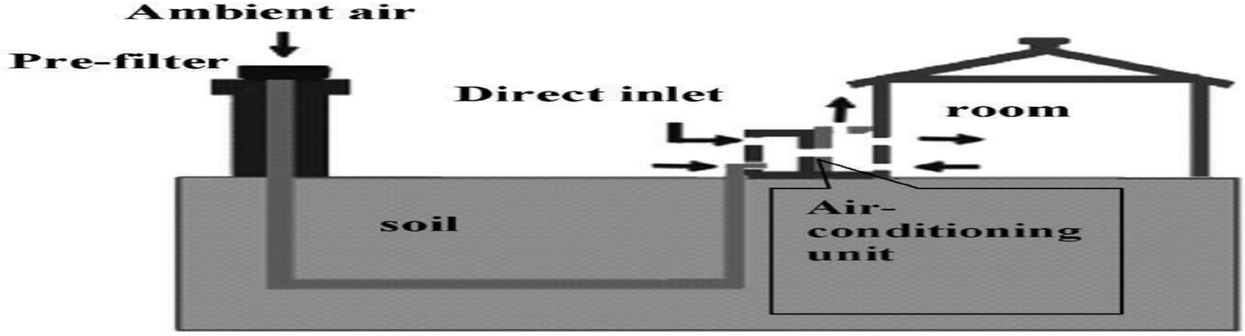


Fig II.2- Basic principle of ground preheating or pre-cooling of air in an open system[26]

Similarly, groundwater from a water-bearing layer can be used as a cooling medium by bringing it into direct contact with the heat pump coils. Typically, two wells are needed: one for extracting the groundwater and another for reinjecting it back into the water-bearing layer, as shown in FigII. 3.

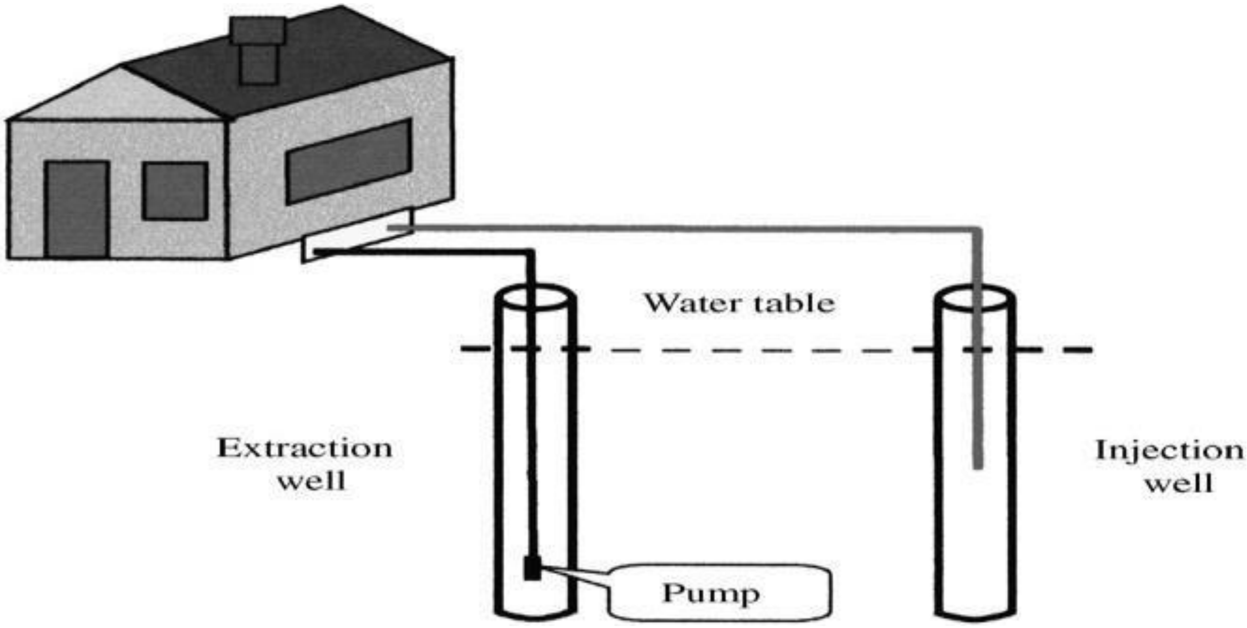


Fig II.3- Ground water heat pump[26].

II.4. 2 Closed systems

In this scenario, heat exchangers are installed underground in horizontal, vertical, or angled positions, using a heat transfer fluid to exchange heat between the ground and a heat pump. The horizontal system, shown in Fig. 4, features pipes arranged in series or parallel and is a cost-effective choice when there is enough space and easy access for digging trenches 1-2 meters deep. These systems typically use plastic pipes, with lengths ranging from 35 to 60 meters per kW of heating or cooling capacity. Horizontal loops are easiest to install during construction but can also be retrofitted into existing buildings with minimal disruption using horizontal boring equipment. Specialized heat exchangers with coiled "slinky" pipes optimize space in shorter trenches. For heating-only systems, solar radiation is the primary thermal recharge source, so the ground surface above the heat collector should not be covered. Vertical ground heat exchangers, known as borehole heat exchangers, are also used in some cases.

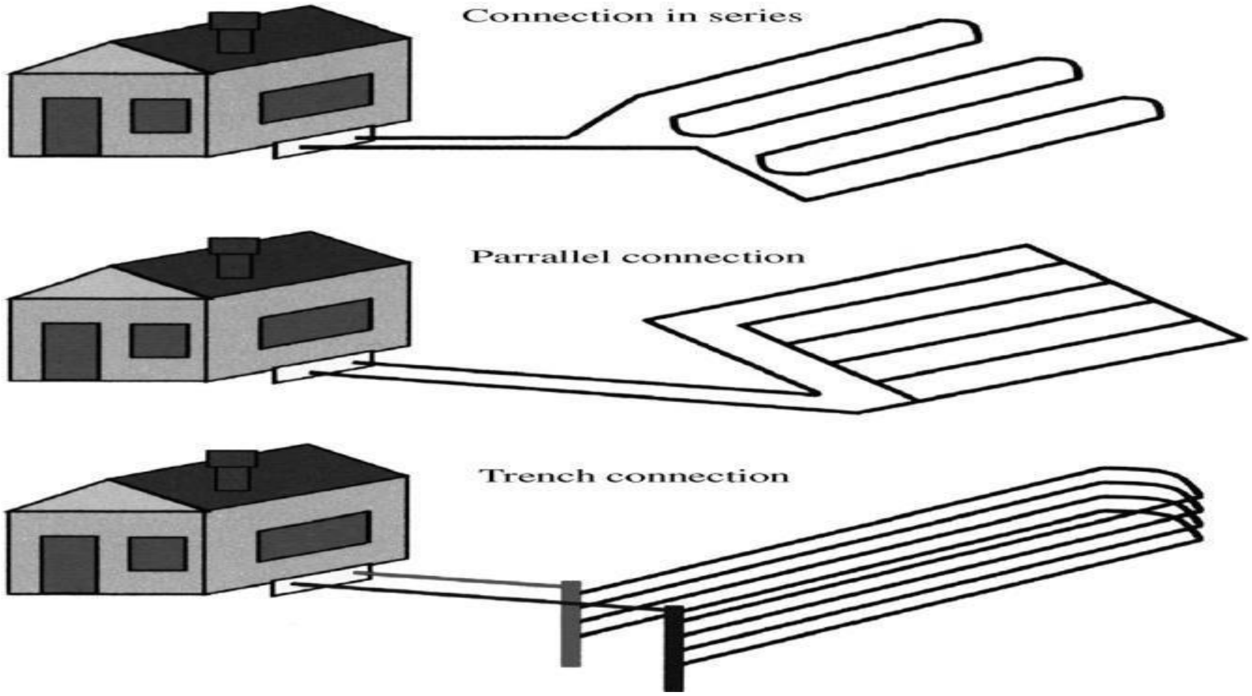


Fig II-4- Horizontal-type ground heat exchangers[26].

Fig II-5- ‘‘Slinky’’-type ground heat exchanger[26].

A confined surface area, such as when the Earth is rocky near the surface or where minimal landscape disruption is desired, makes this possible. This is because the temperature below a certain depth remains constant throughout the year (see Fig. 1). In a standard borehole, typically 50–150 meters deep, plastic pipes (made of polyethylene or polypropylene) are installed. The space between the pipe and the hole is filled with a suitable material to ensure optimal contact between the pipe and the undisturbed ground, thus minimizing thermal resistance.

II.4.3 Common vertical ground heat exchanger designs

Vertical loops tend to be more expensive to install, but they require less piping than horizontal loops because the ground deeper below the surface remains cooler in summer and warmer in winter compared to the surrounding air temperature. Various types of borehole heat exchangers have been tested and are commonly used. These are categorized into two main types, as shown in Fig. 6:(a) U-pipes, which consist of two straight pipes connected by a U-turn at the bottom. Due to the low cost of the pipe material, two or even three U-pipes are typically installed in a single borehole.

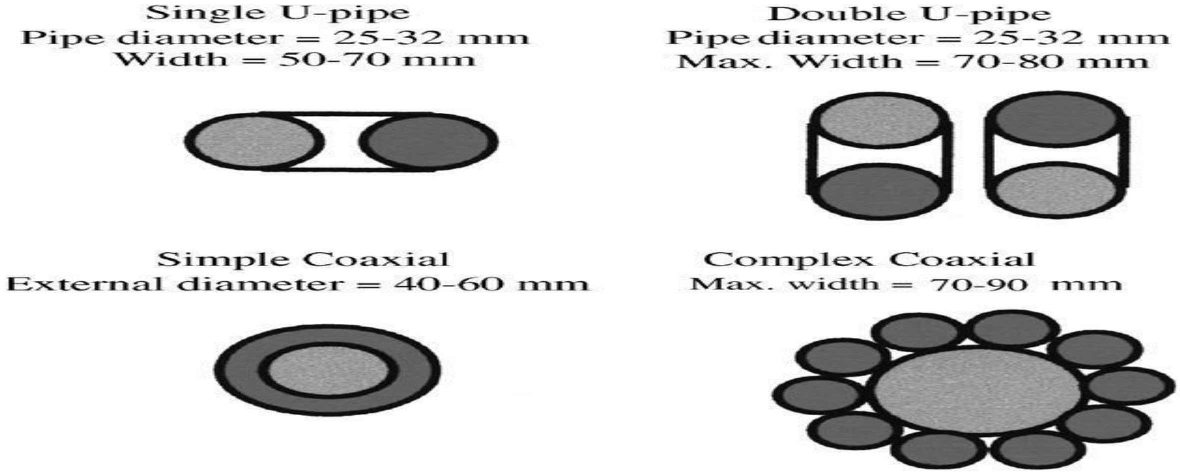


Fig II-6-Common vertical ground heat exchanger designs[27]

II.5 Miscellaneous systems

Some ground systems cannot be classified as either open or closed. One such system is the standing column well, as shown in Fig. 8, where water is pumped from the bottom of the well

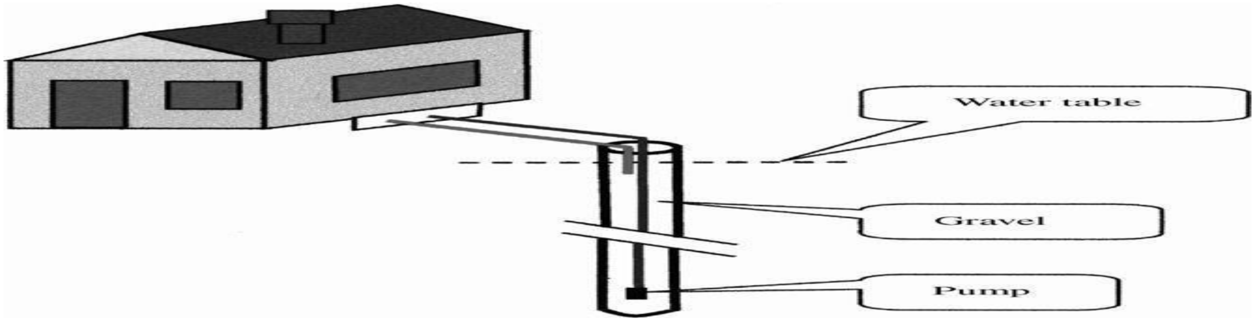


Fig II-7- Standing column a well[27].

to the heat pump. The discharged water is filtered through gravel in the well's annulus to absorb heat. Standing column wells typically have a diameter of 15 cm and can reach depths of up to 500 meters, making them quite costly Other heat sources include water found in mines and tunnels. This water maintains a consistent temperature throughout the year and is readily accessible[28]

II.6 Classification of GAHE

For the EATHE system, a horizontal pipe arrangement is typically preferred as it is more cost-effective to install compared to a vertical pipe system. Within the horizontal EATHE system, there are two main categories of pipe layouts: single- layer and multi-layer. Additionally, depending on the heating/cooling load requirements and land availability, researchers have proposed various pipe layouts for the horizontal EATHE system. Each pipe layout comes with its own set of advantages and limitations.

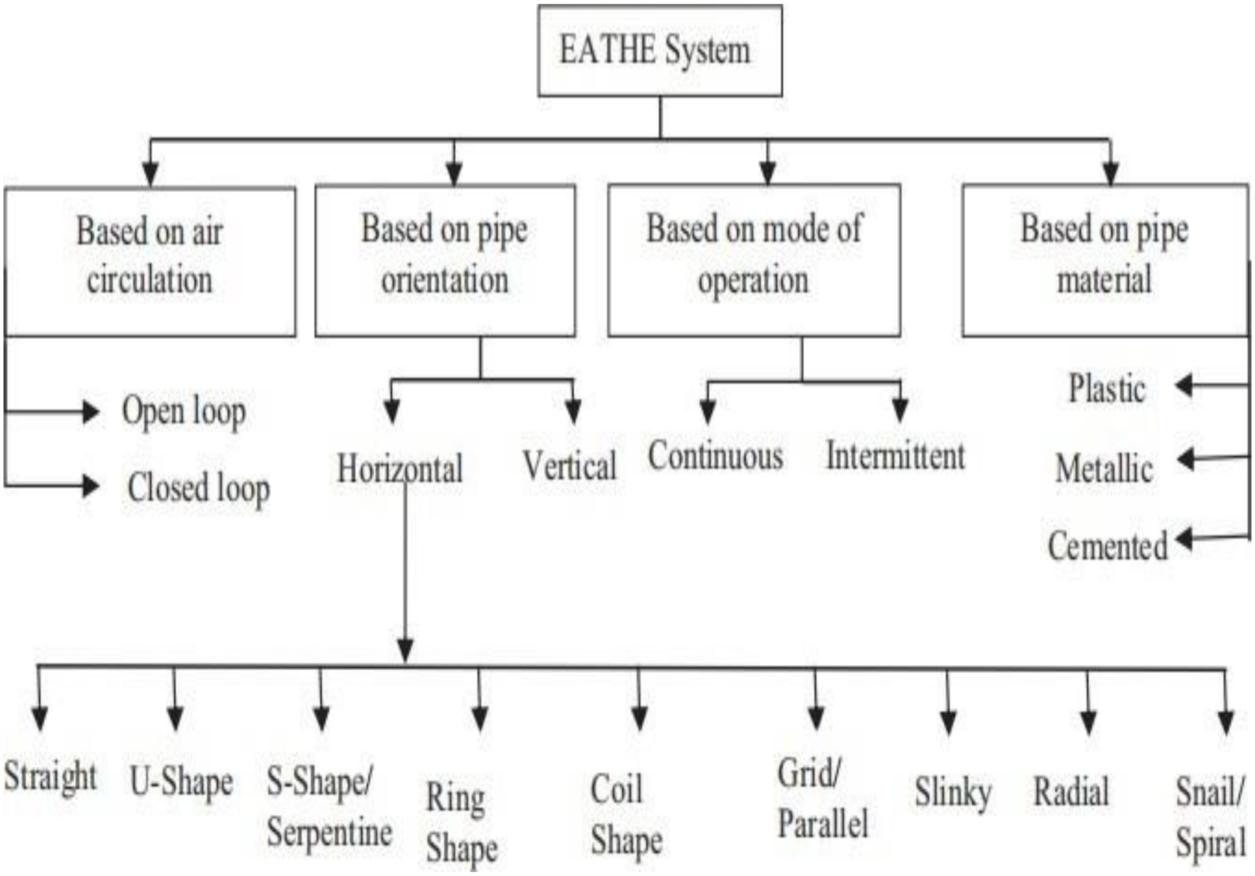


Fig II-8- Classification of EATHE system[29].

II.6.1 Straight pipe

The straight pipe layout is the most commonly used design for a GAHE system because straight pipes are easy to install and result in minimal pressure loss. Therefore, it is the optimal configuration for heating and cooling small buildings. However, this pipe design is only feasible when there is sufficient land available to dig a long trench. Figure 9 illustrates the GAHE system with a straight pipe design [30].

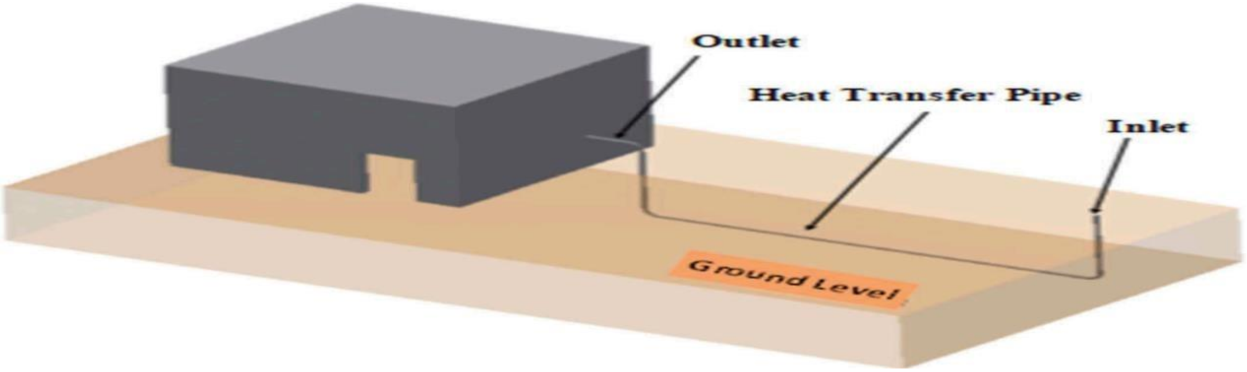


Fig II-9-Straight pipe-layout for GAHE system [31].

II.6.2 U-shape pipe

The U-shaped pipe GAHE system operates similarly to the straight pipe GAHE system, except it features a U-shaped pipe configuration, with both the inlet and outlet located at the same end of the trench (see Figure 10). This system is ideal for applications with low heating and cooling load requirements.

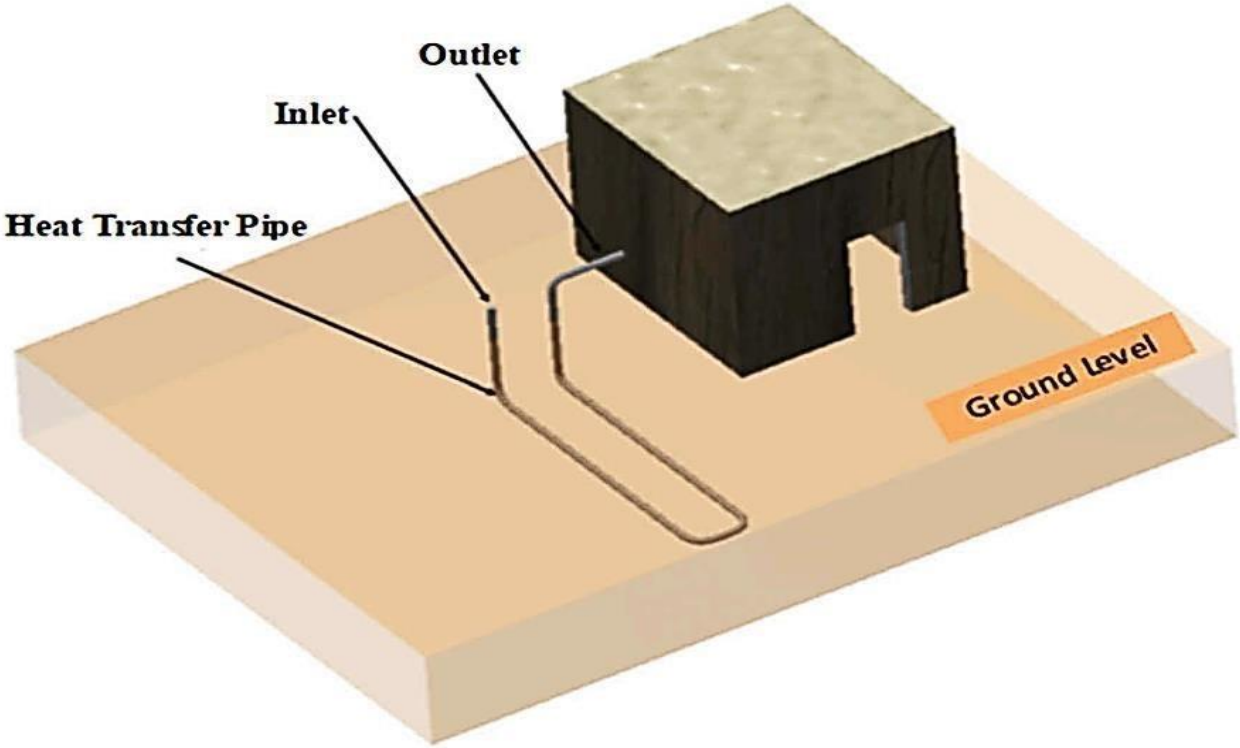


Fig II-10- U-shaped pipe-layout for GAHE system[31]

II.6.3 Ring pipe layout

In the ring pipe layout, the GAHE pipe is embedded within the building's foundations (Figure 11). This pipe arrangement is the most cost-efficient option as it eliminates the need for excavation by utilizing the existing trench in the building's structur.

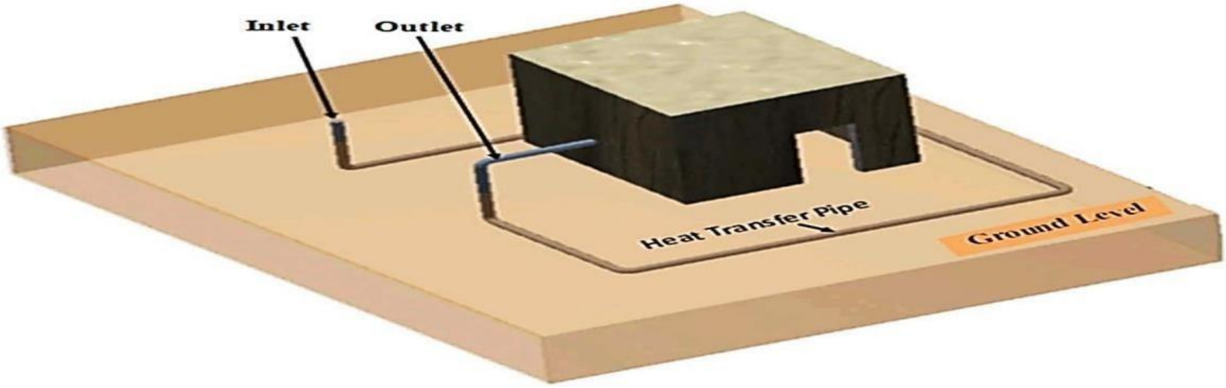


Fig II-11-: Ring pipe-layout for GAHE system [31]

II.6.4 Serpentine pipe layout

The serpentine pipe configuration shown in Figure 12 enables a long pipe to be installed in a short trench by incorporating multiple turns. As a result, it is an ideal design for medium- sized GAHE systems.

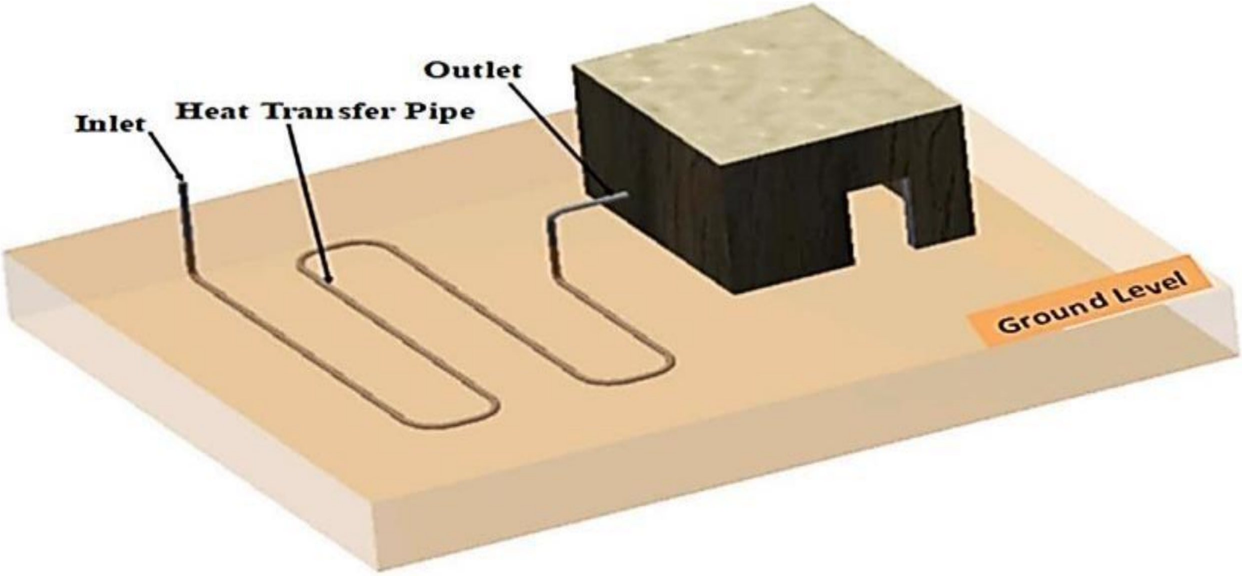


Fig II-12- Serpentine pipe-layout for GAHE system [31]

II.6.5 Spiral pipe-layout

Straight and U-shaped GAHE pipes typically require long trenches with a high aspect ratio (the ratio of trench length to width). However, in densely populated urban areas, the space required for such extensive excavation is often unavailable, limiting the use of these systems. As a result, the spiral pipe-layout (illustrated in Figure 13) has emerged as an alternative, requiring shorter trenches with a lower aspect ratio.

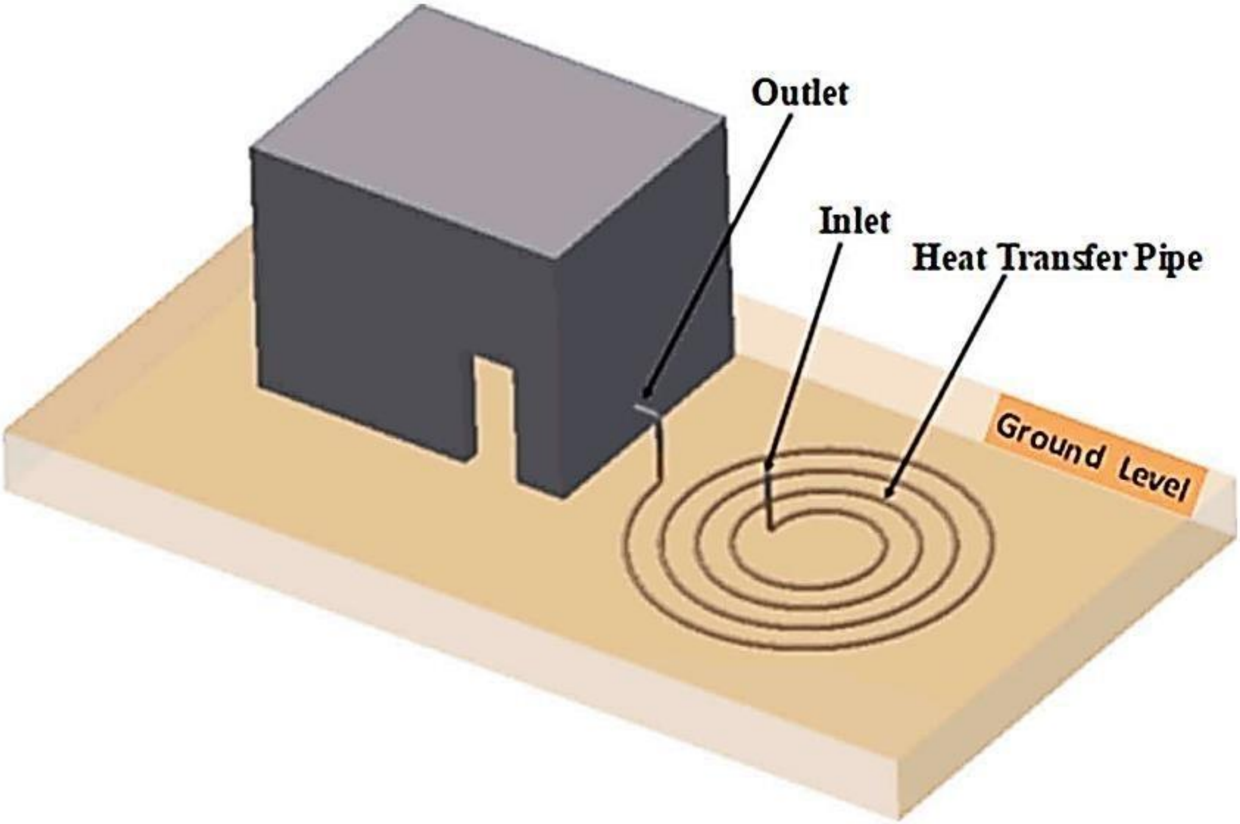


Fig II-13- Spiral pipe-layout for GAHE system[31].

II.6.6 Lateral pipe-layout or parallel pipe-layout

When there is a substantial cooling or heating load and a high airflow rate is required, a lateral or parallel pipe layout is typically employed, as seen in buildings such as schools and hotels. In this setup, multiple heat transfer pipes are connected in parallel to a central header pipe, as shown in Figure 14. While the performance of a parallel pipe layout is effective, it demands a large land area and incurs high excavation costs.

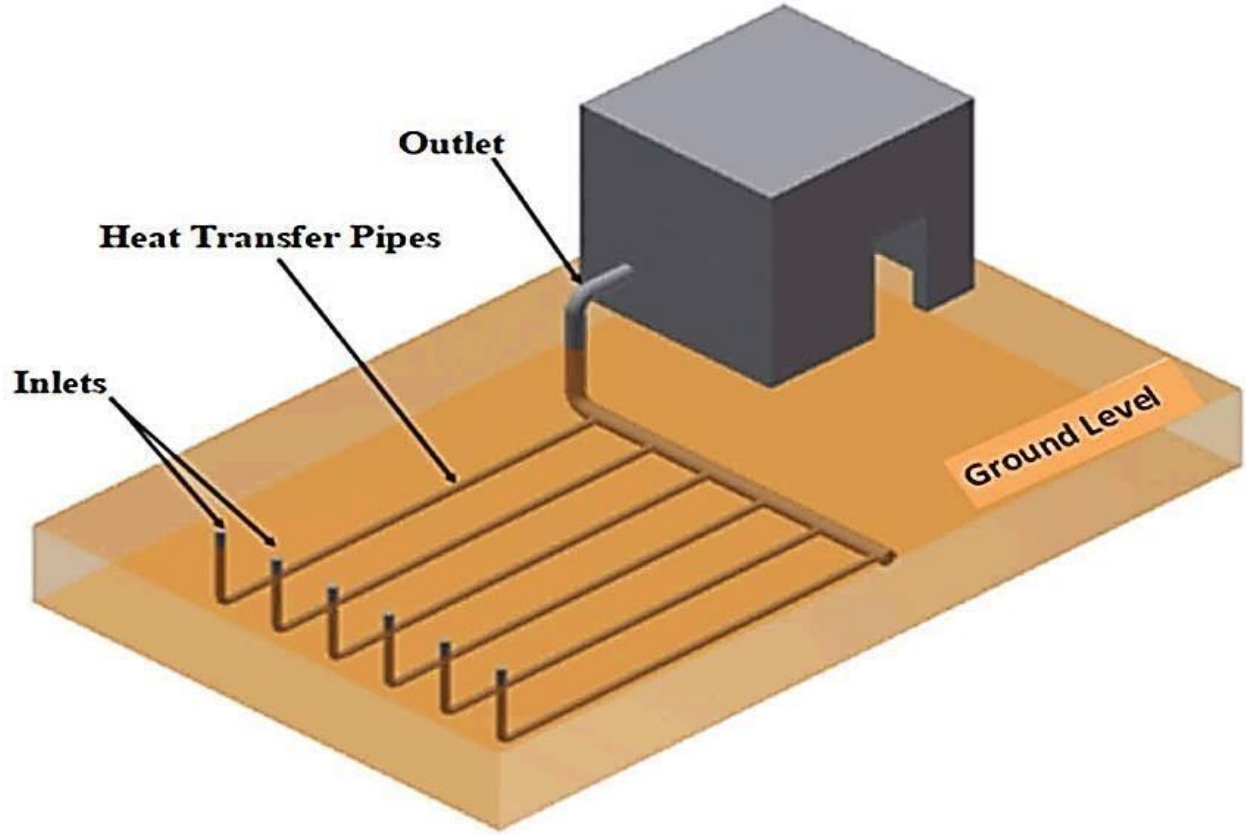


Fig II-14- Lateral pipe-layout for GAHE system[31].

II.6.7 Grid pipe-layout

The GAHE system's grid pipe design utilizes a shared header pipe for both intake and outflow. Ambient air enters through the intake header pipe, circulates through a network of underground pipes, and is then delivered to the room via the exit header pipe, as illustrated in Figure 15 Grid pipe configurations are typically used in large buildings that require pre- tempered air at higher flow rates.

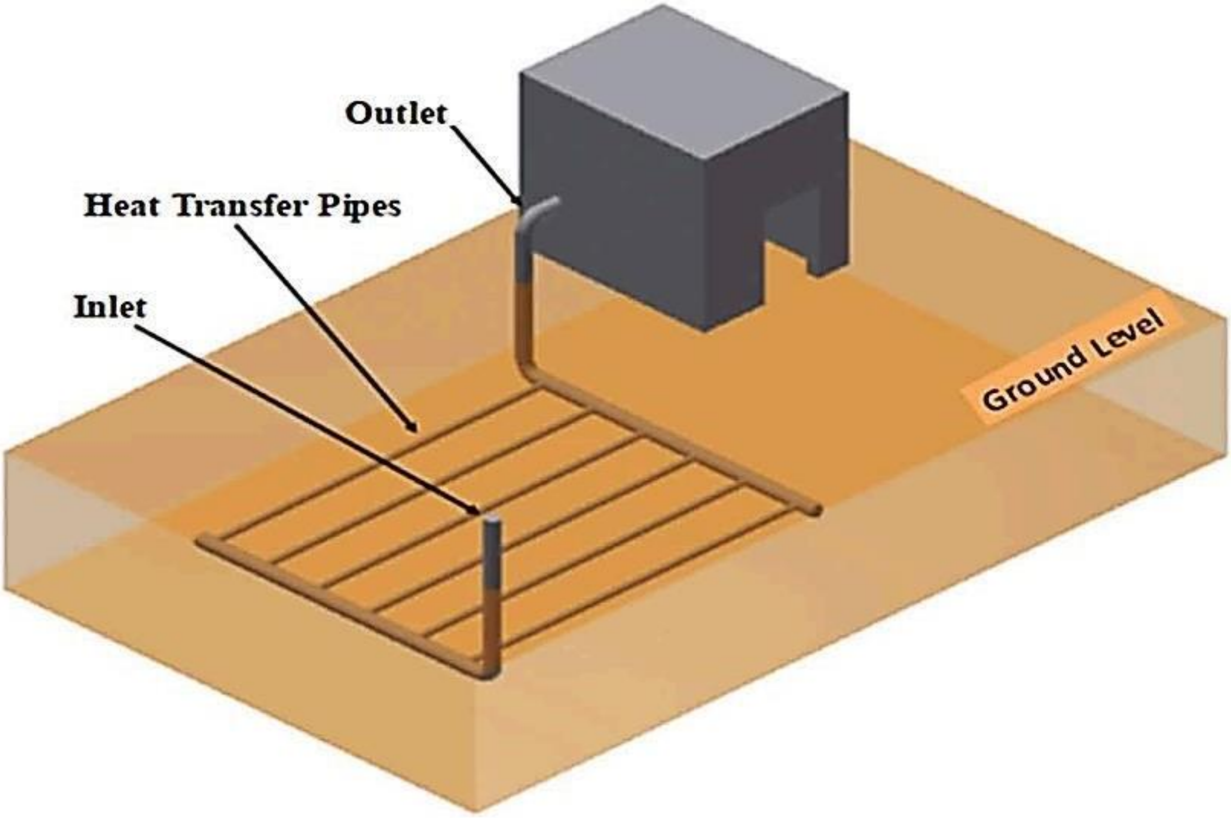


Fig II-15- Grid pipe-layout for GAHE system[31].

II.6.8 Radial pipe-layout

Figure 16 illustrates a pipe layout with radial connections to a common collection tank. This configuration eliminates the need for a manifold pipe, but requires a large collection tank. Radial pipe layouts occupy less land area compared to parallel pipe layouts. However, excavation near the collection tank presents challenges.

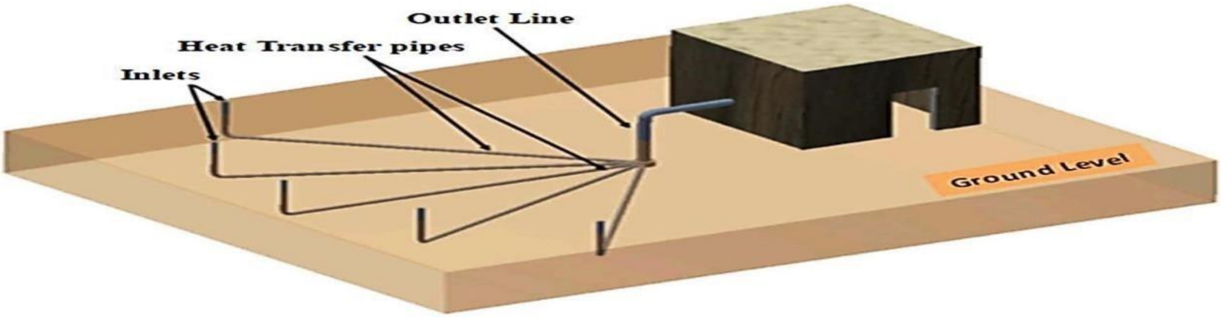


Fig II -16 - Radial pipe-layout for GAHE system[31].

II.6.9 Slinky-coil pipe layout

The slinky coil pipe layout, which minimizes the land area required for extensive pipe installation, is commonly used in horizontal GSHP systems. This pipe arrangement is also ideal for the GAHE system (refer to Figure 17).

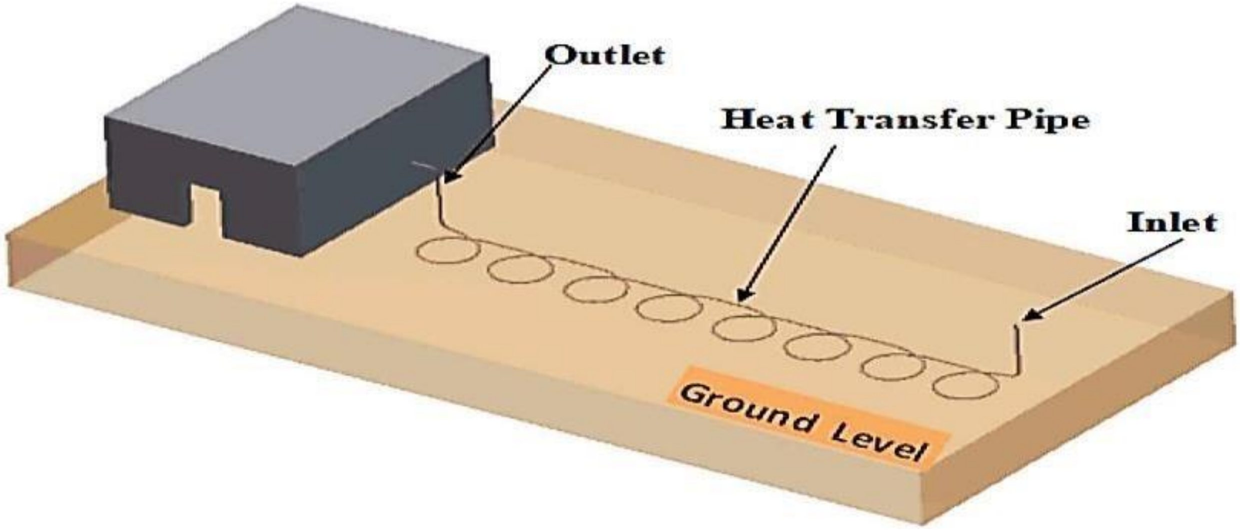


Fig II -17 - Slinky pipe-layout for GAHE system [31]

II.6.10 Helical coil pipe layout

The helical-coil pipe layout is commonly used in GSHP systems due to its minimal land requirements for installing long pipes. This layout can also be applied to GAHE systems (as illustrated in Figure 18), although the installation of large diameter pipes (0.2–0.3 m) presents challenges.

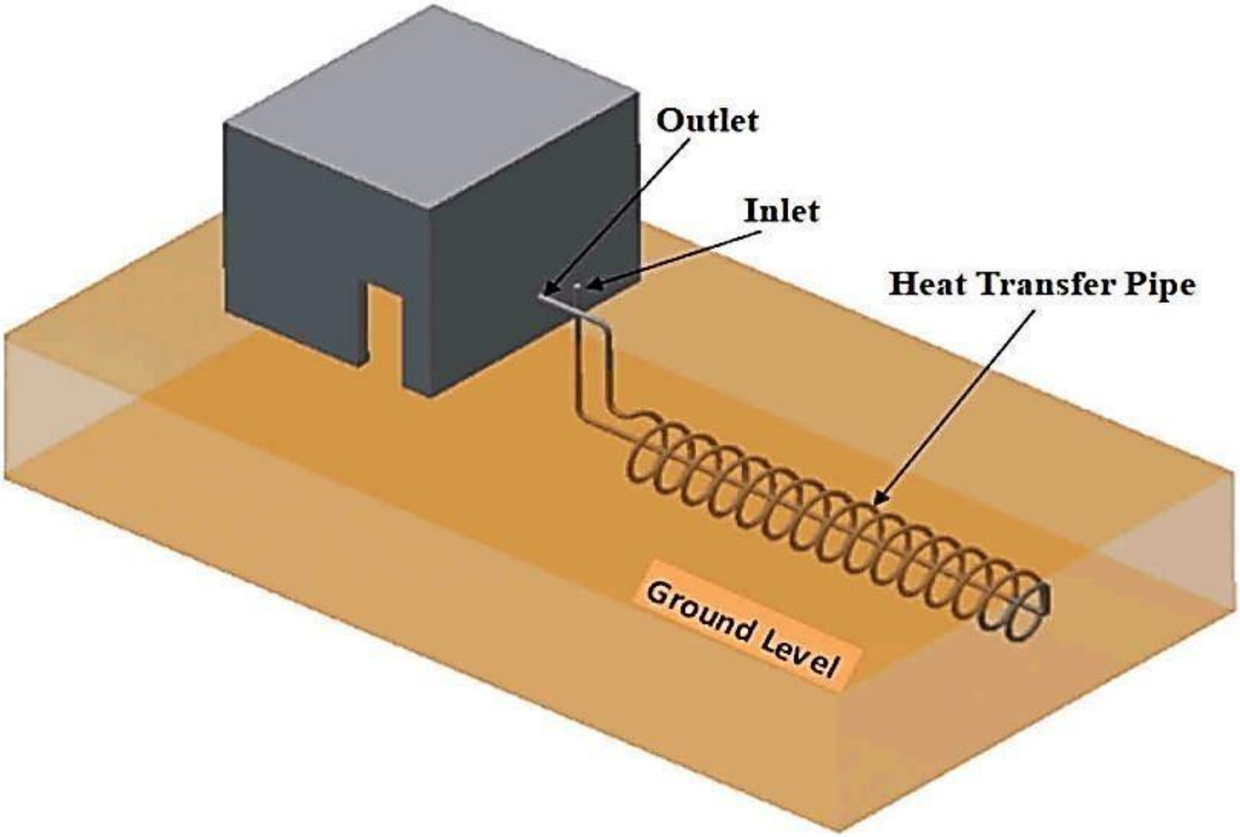


Fig II -18 - Helical pipe-layout for GAHE system[31]

II.7 Ground thermal behavior

The significance of understanding ground thermal behavior is crucial when utilizing direct or indirect earth-coupling methods for buildings and agricultural greenhouses. It highlights that several factors, such as the ground's structure and physical properties, surface cover, and climate conditions, play a role in determining the temperature distribution beneath the surface. The main points discussed include[32].

II.7.1 Ground Temperature Profile

The temperature distribution at any depth beneath the Earth's surface typically remains consistent throughout the year. Temperature increases with depth at an average rate of approximately 30°C per kilometer. However, this gradient can vary depending on the type of rock and ground materials present. Heat flow, an important factor in heat exchanger design, is calculated by multiplying the geothermal gradient by the thermal conductivity of the ground[33].

II.7.2 Thermal Conductivity and Heat Flow

Different types of rocks have different thermal conductivities. For instance, quartz-rich rocks like sandstone possess high thermal conductivity, whereas rocks containing clay or organic materials, such as shale and coal, have lower conductivity. These variations influence the heat flow within the Earth. Rocks with low conductivity (e.g., shale) lead to a higher geothermal gradient, while rocks with high conductivity (e.g., sandstone) produce a lower geothermal gradient, assuming no fluid movement[23].

II.7.3 Ground Surface Temperature Prediction

A model designed to predict daily and yearly fluctuations in ground surface temperature utilizes transient heat conduction equations along with energy balance principles. This model incorporates factors such as convective energy exchange, solar radiation, latent heat flux from evaporation, and long-wave radiation[34].

II.7.4 Energy Balance at Ground Surface

The energy balance at the ground surface is determined by the convective energy exchange between the air and the ground, solar radiation absorption, long-wave radiation emission, and the latent heat flux from evaporation. The equation used to solve for the ground surface temperature[35].

II.7.5 Experimental Validation and Sensitivity Analysis

The model is validated using 10 years of measured data from Athens and Dublin, covering both bare and grass-covered soil. The results are compared with those from Fourier analysis models, and a sensitivity analysis is conducted to examine the influence of various factors on the distribution of soil temperature[36].

II.7.6 Ground Temperature Zones

- Surface Zone (0 to 1 m depth): Extremely responsive to short-term weather fluctuations.
- Shallow Zone (1–8 m for dry, light soils or up to 20 m for moist, heavy soils): Temperature remains relatively stable and closely aligns with the average annual air temperature, mainly influenced by seasonal weather patterns.

- Deep Zone (8–20 m depth): Temperature remains almost constant, with only a gradual increase due to the geothermal gradient[37].

II.7.7 Key Findings from Experimental Studies

- A study conducted in Poznan, Poland, analyzed temperature variations from the summer of 1999 to the spring of 2001. It discovered that short-term temperature fluctuations penetrate to a depth of approximately 1 meter. During the summer, the temperature of bare ground was about 4°C higher than that of ground covered with short grass.
- For heat exchanger applications, it is recommended to use a surface covered with short grass during the summer to ensure a cooler ground source.
- However, in winter, the temperature distributions were almost identical between the bare ground and the grass-covered ground[38].

II.8 Mechanical ventilation

"Dynamic ventilation" utilizes fans to bring air into and circulate it throughout the building. Powered ventilation provides much greater control over the air change rate and airflow, depending on the configuration of the fans, air intakes, and the control systems used. It should be employed only when transitional ventilation is insufficient to maintain a comfortable environment for the chickens. This system is typically used in hot to very hot weather and is more common when the chickens are older. In dynamic ventilation, large volumes of air are drawn through the entire length of the building, quickly replenishing the air. This creates a high-velocity airflow that produces a draft of fresh air to cool the chickens. By adjusting the number of fans operating, the speed of air entering the building can be controlled, which in turn influences the cooling effect on the chickens[25].

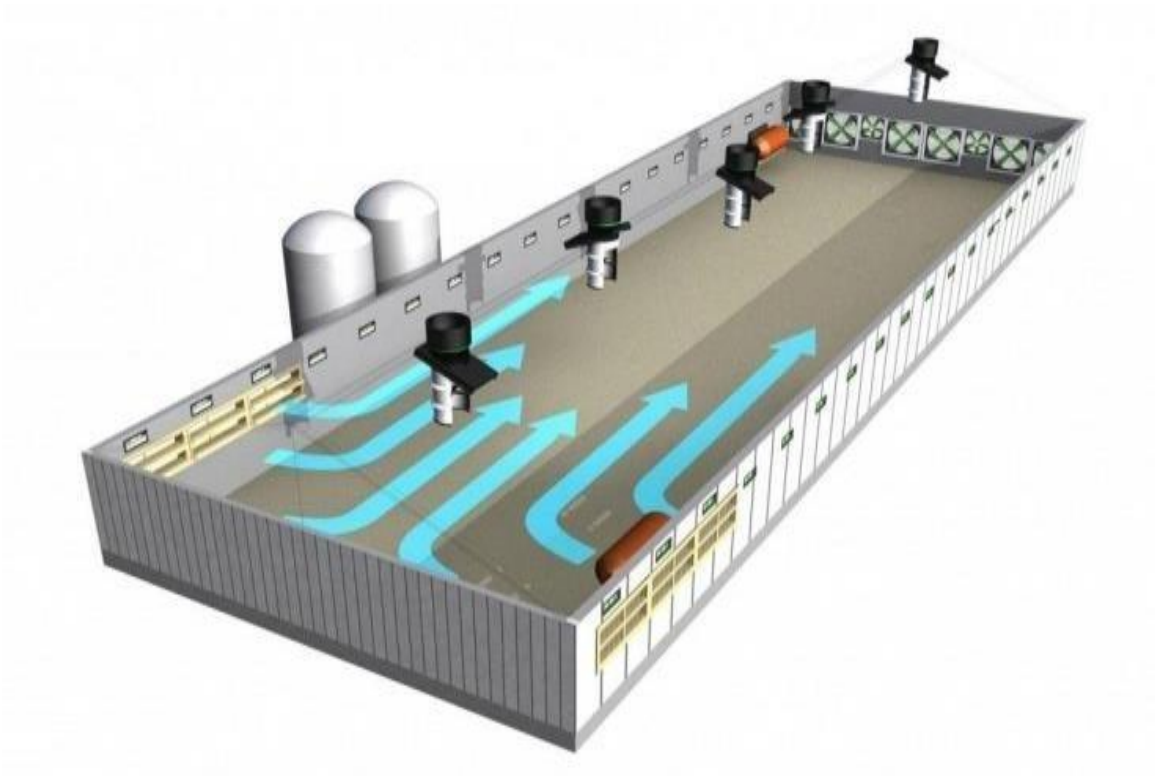


Fig II-19: Tunnel ventilation[39]

II.9 Natural ventilation

Natural ventilation, sometimes referred to as "curtain ventilation," involves opening the building to enable outdoor breezes and convection currents to circulate air throughout the structure. This is usually accomplished by lowering side curtains, shutters, or doors.

However, natural ventilation is only effective when the external conditions closely align with the desired conditions inside the poultry house[40].

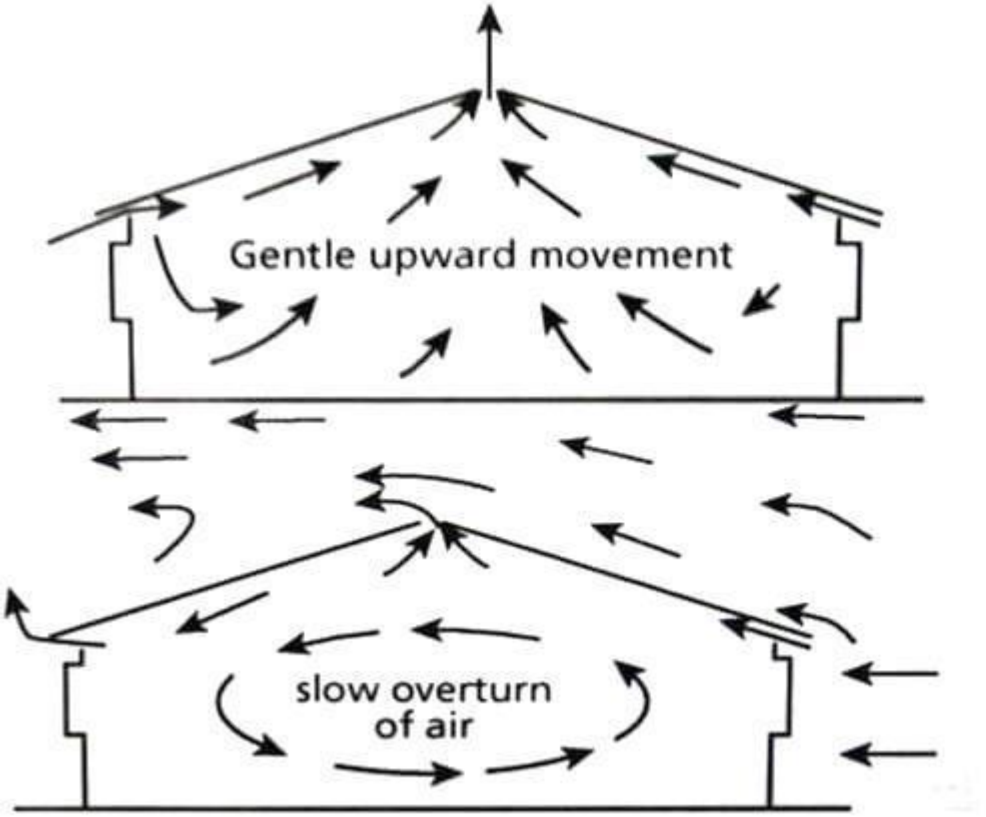


Fig II- 20: Natural ventilation in a poultry house[41].

II.10 Cooling and heating of the building

The GAHE system has been widely implemented worldwide to heat and cool buildings, aiming to enhance energy efficiency and reduce environmental impact. At the RETREAT campus in Gurgaon, India, an earth-air heat exchanger (EAHE) system was used to ventilate the residential quarters (south block). Four tunnels, each 70 meters long and 0.7 meters in diameter, were buried 4 meters underground to manage an airflow rate of 169.9 m^3/min, supported by four blowers, each with a capacity of 2 HP. A solar chimney was also installed to facilitate airflow, as shown in Figure.20. During the summer, the outdoor air temperature was reduced from 42-45°C to 28-30°C. However, in the monsoon season, the increased humidity caused a drop in efficiency, which was mitigated by adding more dehumidifiers and chillers.

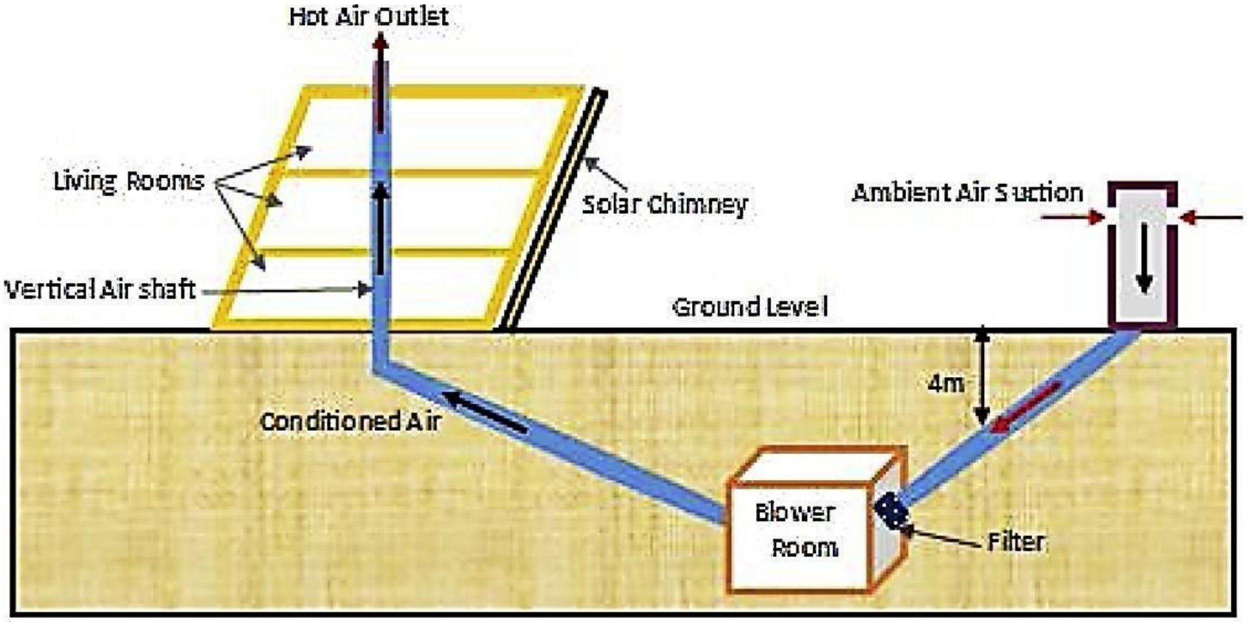


Fig II.21- Schematic diagram of GAHE applications for ventilations of living quarters[17].

II.11 Cooling and heating of livestock

The GAHE system was also employed to regulate the temperature of the air in the tiger enclosure at the Kamala Nehru Zoological Garden in Ahmedabad, India[42]. The system consisted of two MS pipes (0.2 m in diameter and 27 m in length each), installed at a depth of 2 meters in the moat, as depicted in Figure.22. A 1.2 kW blower was used to control the airflow rate at 44.4 m^3/min, resulting in a temperature decrease of 8°C during the summer and an increase of 10°C during the winter.

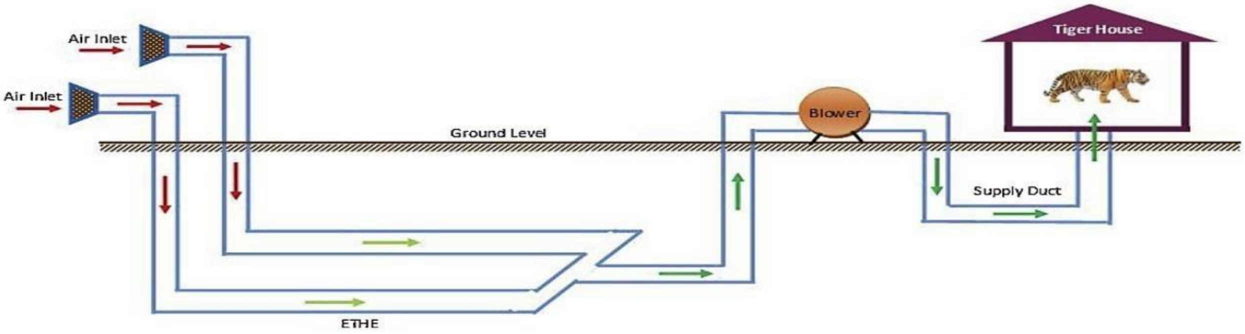


Fig II-22- Schematic of GAHE system application for the dwelling of tigers[43]

II.12 Conclusion

The EATHE or GAHE system is a highly effective passive technique for heating and cooling buildings, offering significant power savings compared to conventional systems. It can function efficiently across various climates and provide pre-tempered air for multiple applications. However, its widespread use is limited by the need for large land areas and high excavation costs. These issues can be alleviated through careful pipe layout design. Key findings from the study include.

Chapter III: Economic evaluation of ground heat exchanger in El Oued region

III.1 Introduction

The Sahara is seen as a kind of empty area that relates to all human activities, a region that people have traveled through, and a place where human life exists in oases and near springs. It serves as a route for trade but also supports the movement of nomads. For the past thirty years, the Algerian Sahara has been undergoing rapid urban development that remains incomplete, with its population growth outpacing that of the rest of the nation. The souf was once a barrier to caravan movement, historically described as a "blind spot." Its urban development was very limited until the 19th century when it started to evolve into a territory shaped by various historical events over time, giving it more significance. This area underwent a range of urbanization processes. The old structures, considered part of Saharan architectural history, along with the former European villages laid out in a grid, were followed by the development plan of Daïra after 1984. Once merely a border zone, it has now transformed into one of the three major cities in the Low-Sahara, alongside Biskra and Touggourt. It has become a key regional center within the national urban landscape as it progressed through various planning phases, leading to the expansion of its area.

III.2 Description of study region

El Oued region (Souf) is situated in the southeastern part of Algeria, nestled against the northern edges of the Grand Erg Oriental, between latitudes 33° and 34° north, and longitudes 6° and 8° east. Covering approximately 350000 hectares, it borders Tunisia and Libya (FigIII.1). This vast Sandy expanse lies roughly equidistant from the Mediterranean Sea to the north and the southern boundary of the Grand Erg Oriental to the south, while also being equal distances from the Gulf of Gabes in the east and the Saharan Atlas in the west[44]. This unique location results in a warm, arid climate that is well-suited for palm farming and provides favorable conditions for trade via caravans. However, this advantageous situation is not as impactful today due to the rise of cars, which has reduced distances and encouraged nomadic and semi-nomadic herders to settle down. Surrounding the Souf are: El-Djerid Chott (in the Tozeur area) to the east, Chott Melghir and Chott Merouane to the north (located in Biskra), Oued-Righ (in Touggourt) to the west, and the Oriental Erg to the south.The Souf covers an area of 80,000 square kilometers and comprises a dune system that stretches 650 kilometers from the Libyan border (Ghadames) to the nearby northern Sebkhas, with a width of about 160 kilometers. The average height of the Souf is 80 meters, whereas the northern Chotts drop below 35 meters above sea level. In the northern region of the Souf, the

Grand Erg Oriental diminishes, transforming from dunes into clay and limestone plateaus that feature sparse vegetation, leading to dry and barren areas. This final section of the desert, though having minimal scrub, can become excellent grazing land after adequate rainfall. The urban clusters discussed in this text include Guemar, Taghzoute, Kouinine, El Oued, Bayadha, and Robbah [45].

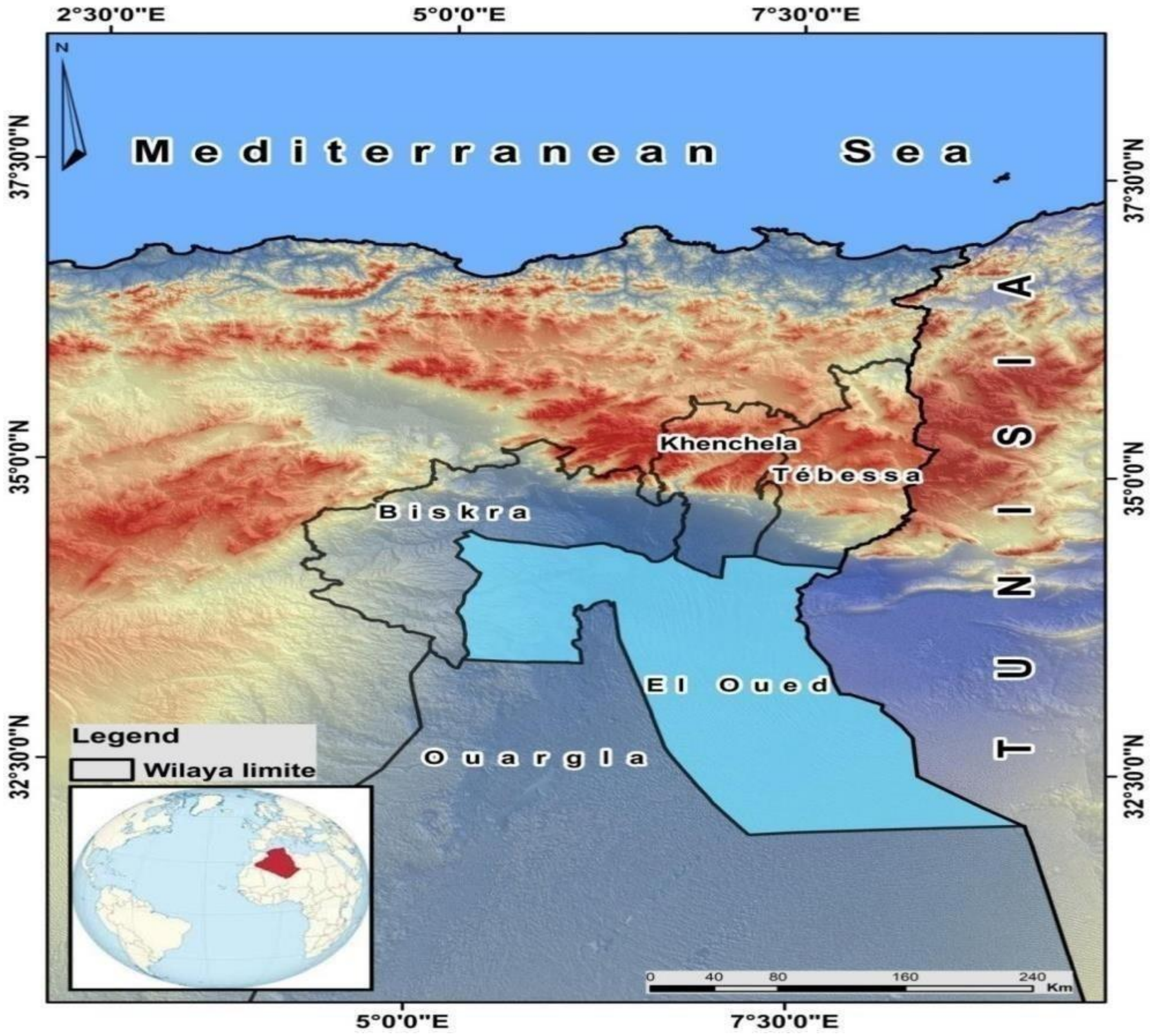


Fig III.1-Study area location map[45]

III 3 Initial Investment Cost.

Installation costs vary depending on the excavation depth, soil type, and system characteristics (whether horizontal or vertical). While the initial cost may be relatively high compared to traditional systems, the system's long lifespan (exceeding 25 to 30 years) helps reduce financial burdens in the long run.

III.3.1 Excavation and installation of a heat exchanger system in a poultry house

In this experimental setup (FigIII.2), a poultry house in the ElOued region containing 6000 chickens was chosen as a case study. To circulate air through the soil, fifteen stretches of buried conduits, or fifteen EAHE conduits, were planned, as shown in the figure. The heat exchangers, made of PVC, with diameters of 110 and 200 mm, were buried at a depth of 4.5 meters, and were combined with seven electrically powered fans to pump air into the conduits. FigIII.2 illustrates the implementation of the EAHE experimental setup in ElOued region.

FigIII.2 Exprimental setup

III.3.2 System Equipment and cost invisment (Ci)

TableIII.1 Equipments and cost invisment

Equipment	**Unit prices HT (cost excluding tax) DZD**	**Unit pricesTTC (cost with all taxes included) DZD**	**Quantities**	**Net prices TTC DZD**
Tube PVC Ø 110 L 6 m	1235.29	2100.00	50	105000.00
Tube PVC Ø 200 L 6 m	2794.11	4750.00	120	570000.00
Insulating layer	4705.88	8000.00	4	32000.00
Elbow 90° PVC Diam.110 mm	70.58823529	120.00	50	6000.00
Fan 210 Watts	23529.41	40000.00	7	280000.00
Electrical wire 100 m	35294.11	60000.00	1	60000.00
Cost of drilling and workers	400000.00			400000.00

Based on the actual experience achieved within the framework of the evaluation, an estimated offer with tax is presented; the total cost of the investment including tax is 1453000 DZD. A summary of the investment cost details is shown in TableIII.1.

III.4 Maintenance cost (Cm)

TableIII.2 Maintenance cost during 30 years.

Time(year)	Cm(DZD)
1	2000
2	4000
3	6000
4	8000
5	10000
6	12000
7	14000
8	16000
9	18000
10	20000
11	22000
12	24000
13	26000
14	28000
15	30000
16	32000
17	34000
18	36000
19	38000
20	40000
21	42000
22	44000
23	46000
24	48000
25	50000
26	52000
27	54000
28	56000
29	58000

30	60000

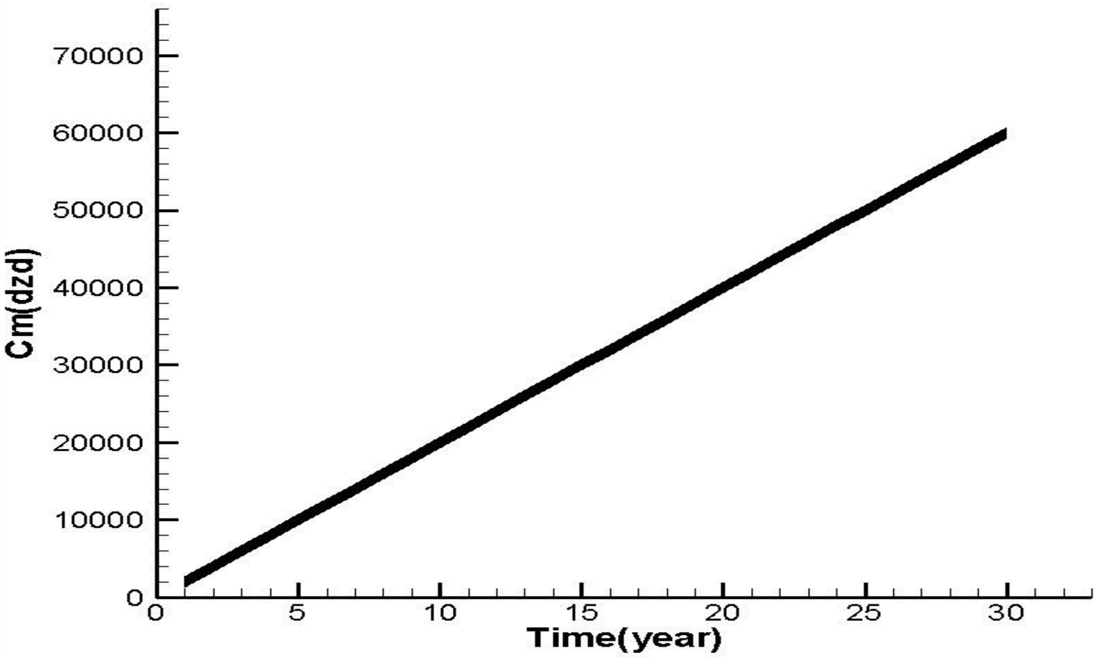


Fig III-3-The total cost of maintenance throughout 30 years

Fig III.3 and TableIII.2 show maitenanace cost of system during thirty years . The curve represents a gradual increase in the annual maintenance costs of ground heat exchangers over a period of 30 years. Although the yearly maintenance cost is relatively low (around 2000 DZD per year), the cumulative value of these expenses reaches 60,000 DZD after 30 years. This highlights the importance of considering such costs when conducting a long-term economic evaluation.

III.5 Energy cost (Ce)

The geothermal system consists of seven electric fans, each with a capacity of 210 watts, operating for 24 hours over a period of 45 days. This process is repeated five times a year.

TableIII.3 Electricity cost during 30 years.

Time(year)	Ce (DZD)
1	31752
2	63504
3	95256
4	127008
5	158760
6	190512
7	222264
8	254016
9	285768
10	317520
11	349272
12	381024
13	412776
14	444528
15	476280
16	508032
17	539784
18	571536
19	603288
20	635040
21	666792
22	698544
23	730296
24	762048
25	793800
26	825552
27	857304
28	889056

29	920808
30	952560

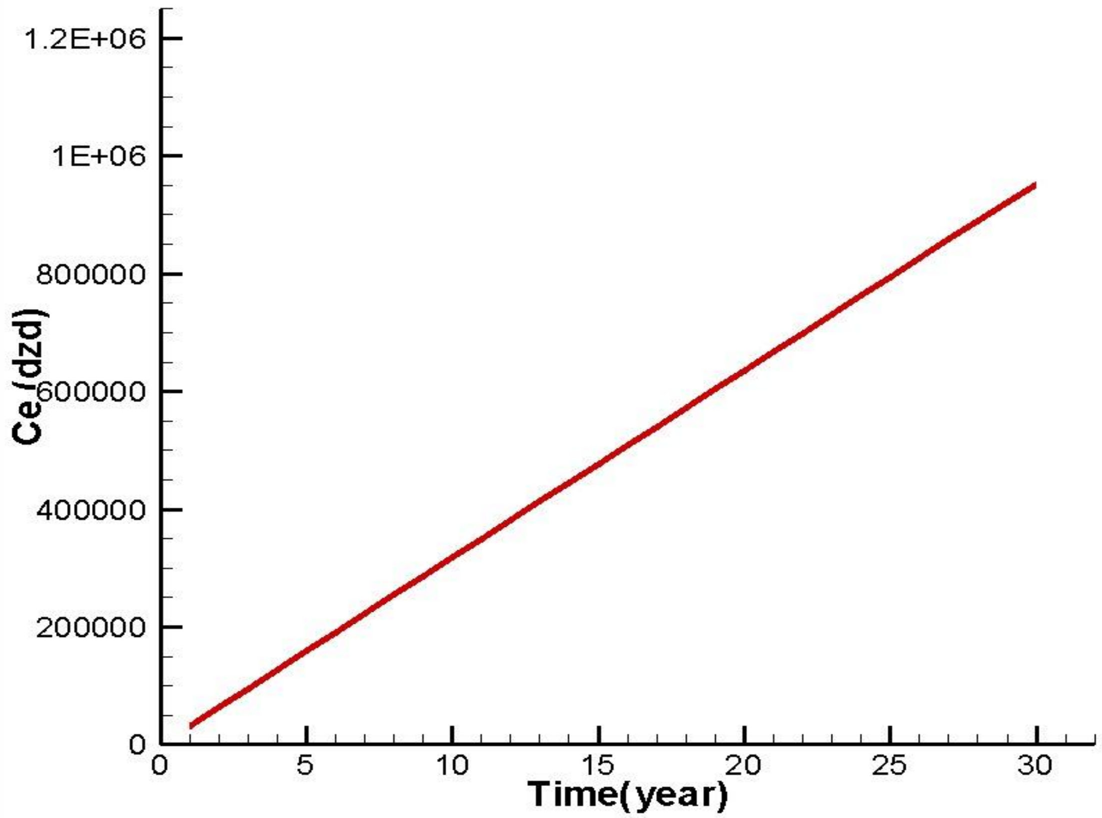


Fig III.4-The total electricity consumption cost over 30 years.

In Algeria, the cost of state-subsidized electricity is approximately 4.1 Algerian dinars. The curve (Fig III.4) illustrates a steady increase in electricity consumption over a 30-year period, with an approximate annual rise of 35000 Algerian DZD. While this increase may appear negligible in the early years, the cumulative cost becomes significantly burdensome over time, particularly in the context of continually rising energy prices.

This trend highlights a growing financial strain on households and businesses alike. It clearly demonstrates that a total reliance on conventional air conditioning systems known for their high electricity consumption is not a sustainable long-term solution, both economically and environmentally.

Therefore, the curve underscores the urgent need to seek alternative, energy-efficient solutions, such as ground heat exchanger (GAHE) systems, which leverage the stable underground temperatures to reduce electricity demand and operating costs.

From an analytical standpoint, the curve serves as a valuable tool for evaluating the economic feasibility of investing in alternative technologies. It can help determine the payback period and long-term benefits of switching to low-consumption systems, encouraging smarter energy planning and more sustainable infrastructure development.

III.6 System cost (Cs)

TableIII.4 System cost during 30 years.

Time(year)	Cs (DZD)
1	1486752
2	1520504
3	1554256
4	1588008
5	1621760
6	1655512
7	1682264
8	1723016
9	1756768
10	1790520
11	1824272
12	1858024
13	1891776
14	1925528
15	1959280
16	1993032
17	2026784
18	2060536
19	2094288
20	2128040
21	2161792
22	2195544
23	2229296
24	2263048

25	2296800
26	2330552
27	2364304
28	2398056
29	2431808
30	2465560

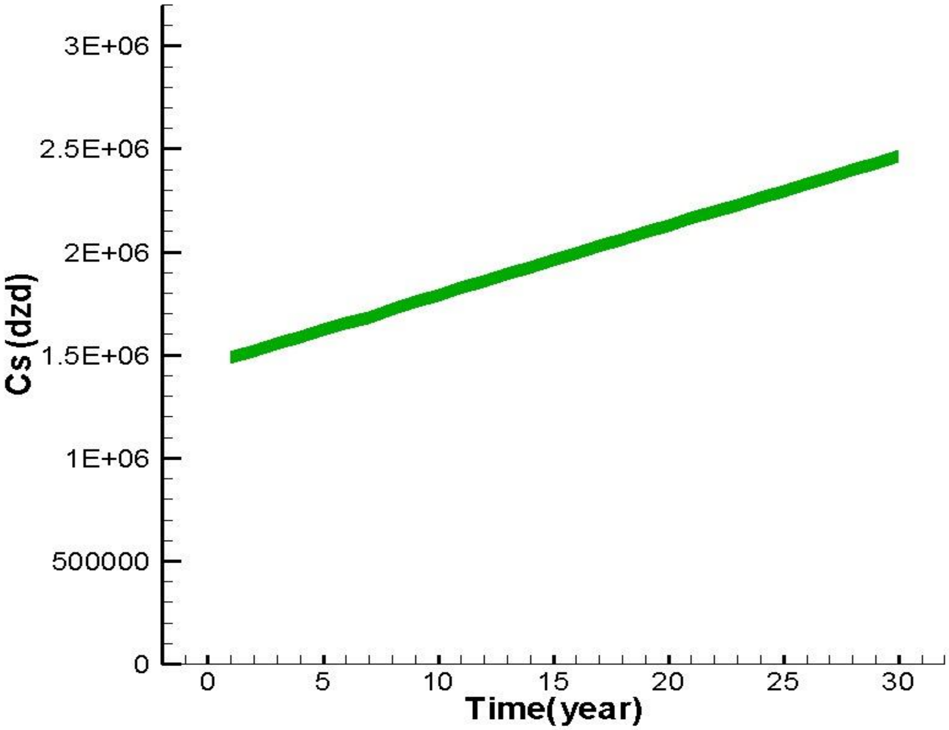


Fig III.5- The total cost of the project

The following equation gived the cumulative investment cost of the heat exchangers system examined, given as a function of the investment cost, electricity consumption cost, and maintenance cost.

$$Cs = Ci + N\,(Ce + Cm) \qquad \text{(III.1)}$$

The graph in Fig III.5 shows the development of the total annual cost over a 30-year period, with a consistent upward trend in costs year after year. The cost starts at 1,486,752 Algerian Dinars in the first year, and then gradually rises to 2,465,560 Dinars in 30 year, with an approximate annual increase of about 33,672 DZD. Based on the details you've provided.

- The cost in the first year is 1,486,752 DZD.

- The cost in the 30 year is 2,465,560 DZD.
- The estimated annual increase is 33,672 DZD. To calculate the total increase in cost over 30 years.
- The difference between the cost in 30 year and 1 year is: 2,465,560 - 1,486,752 = 978,808 DZD.
- Dividing this difference by 29 years (since the increase starts from the second year):

978,808 ÷ 29 = 33,672 DZD.

This shows that the annual increase is constant, indicating that there is a consistent operational or maintenance cost that rises steadily over the 30- year period. This might suggest investments in system performance, equipment upgrades, or maintenance costs that gradually increase over

III.7 CO_2 emission ($E_{CO}2$)

TableIII.5 CO_2 emission during 30 years.

CO_2 emission (kg)	Time(year)
4350.024	1
8700.048	2
13050.072	3
17400.096	4
21750.12	5
26100.144	6
30450.168	7
34800.192	8
39150.216	9
43500.24	10
47850.264	11
52200.288	12
56550.312	13
60900.336	14
65250.36	15
69600.384	16
73950.408	17
78300.432	18
82650.456	19
87000.48	20
91350.504	21
95700.528	22
100050.552	23
104400.576	24

108750.6	25
113100.624	26
117450.648	27
121800.672	28
126150.696	29
130500.72	30

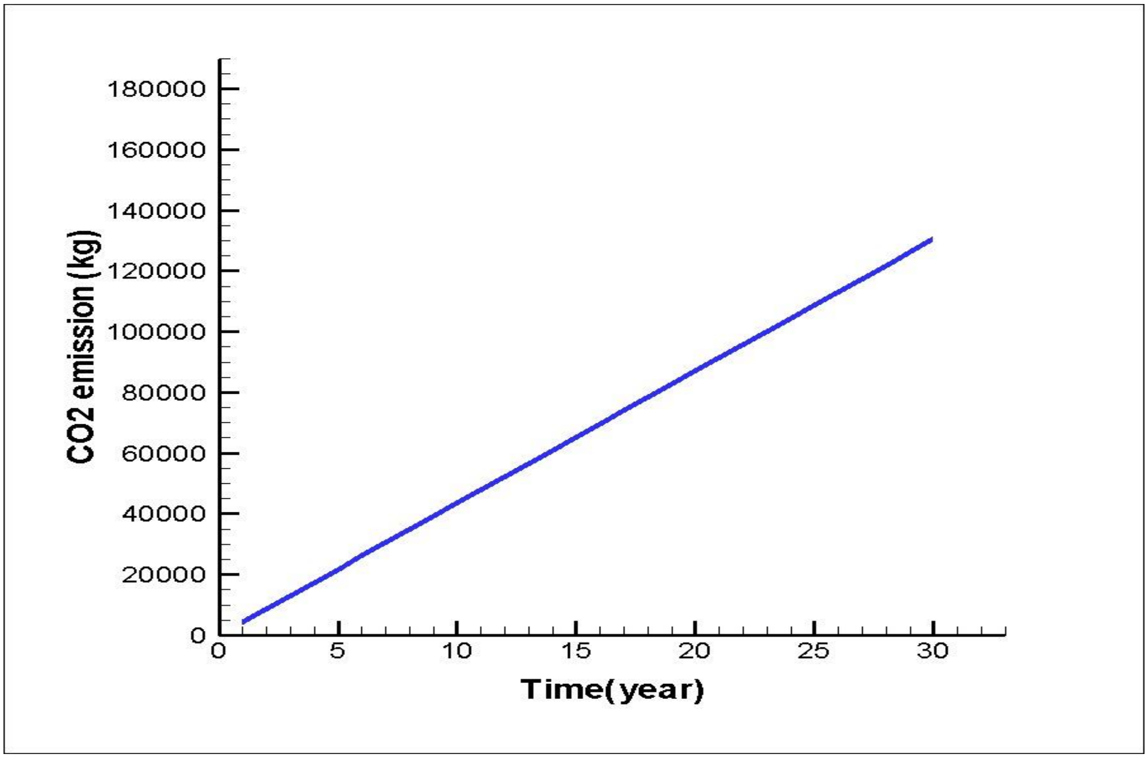


Fig III.6- Carbon Dioxide (CO_2) emission

CO_2 emissions of a heat exchangers system are the CO_2 emissions of 1 kWh per annual electricity consumption and in Algeria, 1 kWh of electricity emits 548g of CO_2.The graph(Fig III.6) presents the development of the amount of carbon dioxide (CO_2) absorbed from external sources over a thirty-year period. It demonstrates a consistent upward trend characterized by a linear and steady increase of 20,000 kg every five years. At the initial point (0), the amount of absorbed CO_2 is zero. This amount then gradually rises to 20000 kg by 5 years and 40000 kg by 10 years, continues increasing at the same rate, eventually reaching a peak of 130000 kg by 30 years.

This regular increase indicates a persistent and predictable accumulation pattern, which may reflect continuous exposure to external sources or stable environmental and operational conditions over time.

III.8 Temperature and Humidity

Traditional poultry houses (TPHs) in Algeria use fuel combustion 100% to provide thermal energy for poultry, especially in the early stages of their life. This causes environmental pollution and expensive. FigIII.7 compares the temperature inside TPH that uses fuel entirely to produce heat, which is considered as a witness, and the temperature coming out of the GHE inside the poultry house. The results show that during the experimental period there is a relative convergence between the temperature provided by the heat exchanger and the temperature produced by the combustion process. As we mentioned previously, the temperature provided by the exchanger is within the limits of 24°C while temperatures provided in traditional poultry farms are between 24°C and 30°C. This comparison proves that sustainable energy can reduce the fuel consumption used in traditional homes, taking into account that the heat exchanger system installed in a simple method. From FigIII.8, it noticed that relative humidity values at GHX outlet are less than the values in TPH. The fan at outlet of GHE increases the convective heat transfer coefficient because of greater turbulence levels. Due to the shorter stay period of air molecules in the pipe, the relative humidity decreased. Meanwhile, the combustion process used in TPH produces vapor with temperature at a value of approximately 30°C caused the relative humidity to reach values of 60 %.

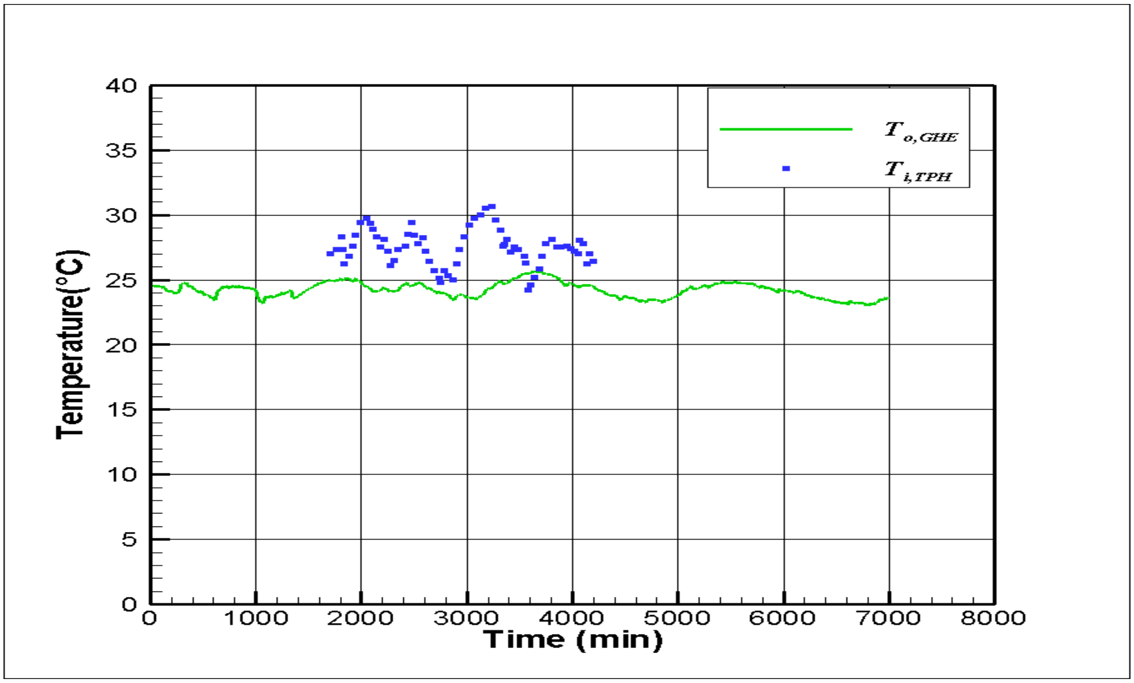


Fig III-7- Comparison of change temperature between GHE outlet and TPH inner

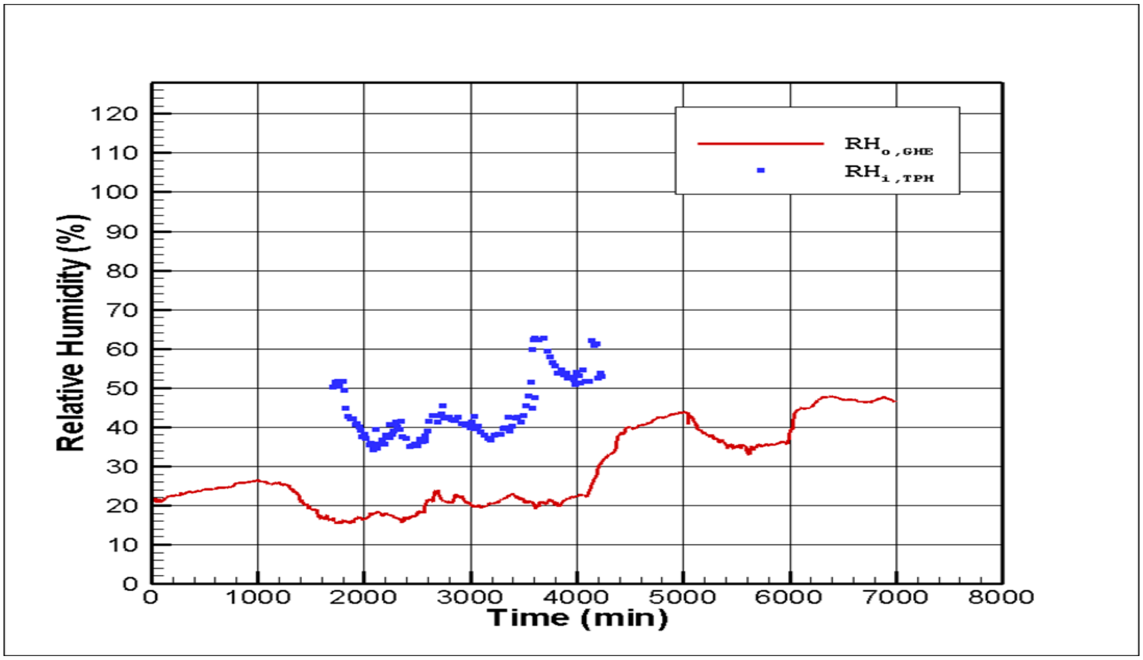


Fig III-8- Comparison of change relative humidity between GHE outlet and TPH inner

III.9 Conclusion

The economic evaluation of ground heat exchanger systems in the El Oued region demonstrates that GHE technology offers a cost-effective and sustainable alternative for thermal energy needs, particularly in residential and small commercial applications. The region’s geological and climatic conditions including sandy soil with good thermal conductivity and a high temperature differential support efficient heat exchange performance.

Despite higher initial installation costs compared to conventional heating and cooling systems, the GHE system exhibits significant long-term savings due to lower operational and maintenance costs. The payback period, while dependent on system size and usage patterns, is generally within a reasonable range (typically 5–10 years), making the investment economically viable. Additionally, the environmental benefits, such as reduced CO_2 emissions and reliance on fossil fuels, further enhance the appeal of this renewable energy solution.

In conclusion, adopting ground heat exchanger systems in El Oued presents both economic and environmental advantages, especially when integrated into broader regional strategies for sustainable energy development.

Conclusion general

The assessment of geothermal heat exchangers reveals that, although they involve significant upfront costs for installation, these systems deliver impressive financial and environmental advantages over time. They are highly efficient in energy use, require very little maintenance, and draw on a renewable energy source, which helps keep operating expenses down. When considering factors like energy savings, tax breaks, and rising electricity costs, geothermal systems frequently yield a good return on investment. For this reason, they are a practical and eco-friendly choice for heating and cooling in both homes and businesses, particularly in regions with favorable soil conditions. Heat pumps can effectively and affordably provide warmth while also minimizing emissions. Geothermal heat pumps are excellent heating solutions that contribute to lower CO_2 emissions, reduce reliance on fossil fuels, and offer economic benefits.Heat pumps are much more energy-efficient for warming buildings compared to other heating methods. Numerous types of geothermal heating systems exist, each designed for various circumstances and most regions worldwide. When choosing a heating solution, it's essential to first evaluate energy use and the expenses associated with implementing a geothermal energy system in three different scenarios. This analysis provides valuable insights for selecting the right type of geothermal facility. Next, the impact of energy cost savings from using geothermal energy was explored, and an efficient strategy was proposed by determining the life cycle cost . This was calculated using both the initial setup and ongoing maintenance costs, with the latter derived from repair and replacement rates unique to the construction features of each system.Many think that the findings of this research can serve as a useful strategy for choosing a geothermal energy facility that is financially viable. Moreover, the impacts on energy savings regarding overall and primary energy use will also provide essential information for understanding and selecting geothermal energy options.The capacity of a new renewable energy facility cannot be determined solely by its energy output. To assess both energy efficiency and economic viability in a more useful manner, one must consider the energy production capability along with the usage efficiency of each facility. Each facility's energy output should be measured according to its unique features, and the potential for energy savings resulting from its implementation must also be taken into account. Future research should focus on examining the energy consumption and cost aspects associated with buildings that incorporate new renewable energy facilities. Moreover, the findings ought to be compared with the energy consumption patterns of buildings analyzed from their design plans to ensure accuracy.

Additionally, a study must be undertaken to develop criteria for selecting suitable facilities, taking into consideration their usage, size, and characteristics based on actual performance data from each new renewable energy facility.

References

[1] M. H. Dickson and M. Fanelli, *Geothermal energy: utilization and technology*: Routledge, 2013.

[2] F. G. Energy, "What is Geothermal Energy?," 2008.

[3] C.-H. Lee, "Renewable and sustainable energy reviews," *Coastal and Ocean,* vol. 5, pp. 62-70, 2012.

[4] B. D. P. Hepburn, "An investigation of the behaviour of the ground in response to energy extraction," Cardiff University, 2013.

[5] K. E. N'Tsoukpoe, H. U. Rammelberg, A. F. Lele, K. Korhammer, B. A. Watts, T. Schmidt, *et al.*, "A review on the use of calcium chloride in applied thermal engineering," *Applied Thermal Engineering,* vol. 75, pp. 513-531, 2015.

[6] M. El Ouali, L. Kabiri, B. Essafraoui, A. Charroud, F.-N. Krencker, and S. Bodin, "Stratigraphic and geodynamic characterization of Jurassic–Cretaceous “red beds” on the Msemrir–Errachidia E–W transect (central High Atlas, Morocco)," *Journal of African Earth Sciences,* vol. 183, p. 104330, 2021.

[7] I. Stober and K. Bucher, "Geothermal energy," *Germany: Springer-Verlag Berlin Heidelberg. doi,* vol. 10, pp. 978-3, 2013.

[8] A. Anderson and B. Rezaie, "Geothermal technology: Trends and potential role in a sustainable future," *Applied Energy,* vol. 248, pp. 18-34, 2019.

[9] N. A. Pambudi, "Geothermal power generation in Indonesia, a country within the ring of fire: Current status, future development and policy," *Renewable and Sustainable Energy Reviews,* vol. 81, pp. 2893-2901, 2018.

[10] G. W. Huttrer, "The status of world geothermal power generation 1995–2000," *Geothermics,* vol. 30, pp. 1-27, 2001.

[11] L. Gong, D. Han, Z. Chen, D. Wang, K. Jiao, X. Zhang, *et al.*, "Research status and development trend of key technologies for enhanced geothermal systems," *Natural Gas Industry B,* vol. 10, pp. 140-164, 2023.

[12] P. M. Wright, S. H. Ward, H. P. Ross, and R. C. West, "State-of-the-art geophysical exploration for geothermal resources," *Geophysics,* vol. 50, pp. 2666-2696, 1985.

[13] T. Ke, S. Huang, W. Xu, and X. Li, "Study on heat extraction performance of multiple-doublet system in Hot Sedimentary Aquifers: Case study from the Xianyang geothermal field, Northwest China," *Geothermics,* vol. 94, p. 102131, 2021.

[14] F. H. Harlow and W. E. Pracht, "A theoretical study of geothermal energy extraction," *Journal of Geophysical Research*, vol. 77, pp. 7038-7048, 1972.

[15] M. E. Zayed, B. Shboul, H. Yin, J. Zhao, and A. A. Zayed, "Recent advances in geothermal energy reservoirs modeling: Challenges and potential of thermo-fluid integrated models for reservoir heat extraction and geothermal energy piles design," *Journal of Energy Storage,* vol. 62, p. 106835, 2023.

[16] R. Bertani, "Geothermal energy: an overview on resources and potential," in *Proceedings of the international conference on national development of geothermal energy use, Slovakia*, 2009.

[17] J. Van Hoof, M. Mazej, and J. L. Hensen, "Thermal comfort: research and practice," *Frontiers in Bioscience,* vol. 15, pp. 765-788, 2010.

[18] A. P. Gagge, J. A. Stolwijk, and J. D. Hardy, "Comfort and thermal sensations and associated physiological responses at various ambient temperatures," *Environmental research,* vol. 1, pp. 1-20, 1967.

[19] L. G. Berglund, "Comfort and humidity," *ASHRAE journal,* vol. 40, p. 35, 1998.

[20] S. Konz, S. Al-Wahab, and H. Gough, "The effect of air velocity on thermal comfort," in *Proceedings of the Human Factors Society Annual Meeting*, 1983, pp. 733-737.

[21] E. Kamalha, Y. Zeng, J. I. Mwasiagi, and S. Kyatuheire, "The comfort dimension; a review of perception in clothing," *Journal of sensory studies,* vol. 28, pp. 423-444, 2013.

[22] C. O. Popiel, J. Wojtkowiak, and B. Biernacka, "Measurements of temperature distribution in ground," *Experimental thermal and fluid science,* vol. 25, pp. 301-309, 2001.

[23] N. Bordoloi, A. Sharma, H. Nautiyal, and V. Goel, "An intense review on the latest advancements of Earth Air Heat Exchangers," *Renewable and Sustainable Energy Reviews,* vol. 89, pp. 261-280, 2018.

[24] K. K. Agrawal, G. D. Agrawal, R. Misra, M. Bhardwaj, and D. K. Jamuwa, "A review on effect of geometrical, flow and soil properties on the performance of Earth air tunnel heat exchanger," *Energy and Buildings,* vol. 176, pp. 120-138, 2018.

[25] R. Hu and J. Niu, "A review of the application of radiant cooling & heating systems in Mainland China," *Energy and Buildings,* vol. 52, pp. 11-19, 2012.

[26] K. K. Agrawal, R. Misra, and G. D. Agrawal, "Improving the thermal performance of ground air heat exchanger system using sand-bentonite (in dry and wet condition) as backfilling material," *Renewable Energy,* vol. 146, pp. 2008-2023, 2020.

[27] M. R. Akhtari, I. Shayegh, and N. Karimi, "Techno-economic assessment and optimization of a hybrid renewable earth-air heat exchanger coupled with electric boiler, hydrogen, wind and PV configurations," *Renewable Energy,* vol. 148, pp. 839-851, 2020.

[28] D. Chattoraj, K. Birdi, D. Chattoraj, and K. Birdi, "Miscellaneous Systems," *Adsorption and the Gibbs Surface Excess,* pp. 385-420, 1984.

[29] B. Poulter, N. MacBean, A. Hartley, I. Khlystova, O. Arino, R. Betts*, et al.*, "Plant functional type classification for earth system models: Results from the European Space Agency's Land Cover Climate Change Initiative," *Geoscientific Model Development,* vol. 8, pp. 2315-2328, 2015.

[30] K. K. Agrawal, R. Misra, G. D. Agrawal, M. Bhardwaj, and D. K. Jamuwa, "Effect of different design aspects of pipe for earth air tunnel heat exchanger system: A state of art," *International Journal of Green Energy,* vol. 16, pp. 598-614, 2019.

[31] K. K. Agrawal, R. Misra, M. Bhardwaj, G. Das Agrawal, and A. Mathur, "Computational fluid dynamics simulation based comparison of different pipe layouts in an EATHE system for cooling operation," *Journal of Thermal Science and Engineering Applications*, vol. 11, p. 051012, 2019.

[32] Ł. Amanowicz, "Influence of geometrical parameters on the flow characteristics of multi-pipe earth-to-air heat exchangers–experimental and CFD investigations," *Applied energy,* vol. 226, pp. 849-861, 2018.

[33] B. Asgari, M. Habibi, and A. Hakkaki-Fard, "Assessment and comparison of different arrangements of horizontal ground heat exchangers for high energy required applications," *Applied Thermal Engineering,* vol. 167, p. 114770, 2020.

[34] S. Gad, M. El-Shazly, K. I. Wasfy, and A. Awny, "Utilization of solar energy and climate control systems for enhancing poultry houses productivity," *Renewable Energy,* vol. 154, pp. 278-289, 2020.

[35] M. Iqbal, M. Azam, M. Naeem, A. S. Khwaja, and A. Anpalagan, "Optimization classification, algorithms and tools for renewable energy: A review," *Renewable and sustainable energy reviews,* vol. 39, pp. 640-654, 2014.

[36] I. Kilic, "Analysis of the energy efficiency of poultry houses in the Bursa region of Turkey," *Journal of Applied Animal Research,* vol. 44, pp. 165-172, 2016.

[37] P. Joshi and G. Tiwari, "Energy matrices, exergo-economic and enviro-economic analysis of an active single slope solar still integrated with a heat exchanger: a comparative study," *Desalination,* vol. 443, pp. 85-98, 2018.

[38] M. Jalali, A. Banakar, B. Farzaneh, and M. Montazeri, "Technical and economic feasibility of using solar energy to provide heat load to a poultry house," *Journal of Agricultural Machinery,* vol. 13, pp. 285-307, 2023.

[39] Y. Zhou, S. Zheng, Z. Liu, T. Wen, Z. Ding, J. Yan, *et al.*, "Passive and active phase change materials integrated building energy systems with advanced machine-learning based climate-adaptive designs, intelligent operations, uncertainty-based analysis and optimisations: A state-of-the-art review," *Renewable and Sustainable Energy Reviews,* vol. 130, p. 109889, 2020.

[40] F. Soflaei, M. Shokouhian, and W. Zhu, "Socio-environmental sustainability in traditional courtyard houses of Iran and China," *Renewable and Sustainable Energy Reviews,* vol. 69, pp. 1147-1169, 2017.

[41] F. Rojano, P.-E. Bournet, M. Hassouna, P. Robin, M. Kacira, and C. Y. Choi, "Modelling the impact of air discharges caused by natural ventilation in a poultry house," *biosystems engineering,* vol. 180, pp. 168-181, 2019.

[42] L. Liu, L. Fu, Y. Jiang, and S. Guo, "Major issues and solutions in the heat-metering reform in China," *Renewable and Sustainable Energy Reviews,* vol. 15, pp. 673-680, 2011.

[43] M. Zeyad, S. M. Ahmed, S. Hasan, E. Hossain, and M. S. T. Anubhove, "Economic feasibility analysis of a designed poultry farming zone with renewable energy resources in Bangladesh," in *2022 Global Energy Conference (GEC),* 2022, pp. 75-79.

[44] Sahel and W. A. Club, *West African Studies Regional Atlas on West Africa*: OECD Publishing, 2009.

[45] A. M. Miloudi and B. Remini, "The ghout of Souf: An original hydroagricultural system," *GeoScience Engineering,* vol. 64, pp. 30-37, 2018.