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An experimental study on thermal performance of geothermal heat exchanger to poultry farming in El Oued region

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Abstract

In Algeria, there is currently a lack of research on ground-based air-heat exchanger (GAHE) technologies, which store heat in the soil. By allowing air to pass through a heat exchanger, the soil acts as a medium for storing heat or coolness. A detailed pilot study was conducted to investigate the thermal performance of ground-based air-heat exchangers in poultry houses. The study model was designed in a U-shape with 15 PVC pipes and an exhaust fan at the end. The study employed a comparative approach to evaluate the air quality inside hybrid and conventional poultry houses. The results showed that the air temperature exiting the heat exchanger remained stable, ranging between 24 and 27°C regardless of the ambient temperature, while the average efficiency of the ground-based air-heat exchangers was estimated to be between 91.13% and 92.56%. Meanwhile, the temperature produced in conventional poultry houses from combustion was close to that produced by the heat exchanger. Ground-based air-heat exchangers maintain moderate relative humidity thanks to the movement and circulation of air molecules generated by the fan. Air-to-ground heat exchangers play a positive role in poultry house ventilation, renewing the air supply within the poultry room during the study period, and allowing for controlled airflow. The application of geothermal energy systems in buildings in Algeria has a promising future due to the availability and natural nature of the resources.

Keywords: GAHE; experimental; temperature; poultry house; thermal efficiency.

الملخص

في الجزائر، يوجد حاليًا نقص في الأبحاث المتعلقة بتقنيات المبادلات الحرارية الهوائية الأرضية، التي تخزن الحرارة في التربة. فمن خلال السماح للهواء بالمرور عبر المبادل الحراري، تعمل التربة كوسيط لتخزين الحرارة أو البرودة. أُجريت دراسة تجريبية مفصلة للتحقق من الأداء الحراري للمبادلات الحرارية الهوائية الأرضية في حظائر الدواجن. صُمم نموذج الدراسة على شكل حرف U، مزودًا بـ 15 أنبوبًا من مادة PVC ومروحة شفط في نهايته. استخدمت الدراسة منهجًا مقارنًا لتقييم جودة الهواء داخل حظائر الدواجن الهجينة والتقليدية. أظهرت النتائج أن درجة حرارة الهواء الخارج من المبادل الحراري ظلت مستقرة، حيث تراوحت بين 24 و27 درجة مئوية بغض النظر عن درجة الحرارة المحيطة، بينما قُدِّر متوسط كفاءة المبادلات الحرارية الهوائية الأرضية بين 91.13% و92.56%. في الوقت نفسه، كانت درجة الحرارة الناتجة عن الاحتراق في حظائر الدواجن التقليدية قريبة من تلك الناتجة عن المبادل الحراري. تحافظ المبادلات الحرارية الهوائية الأرضية على رطوبة نسبية معتدلة بفضل حركة ودوران جزيئات الهواء التي تولدها المروحة. تؤدي المبادلات الحرارية بين الهواء والأرض دورًا إيجابيًا في تهوية حظائر الدواجن، إذ تُجدد تدفق الهواء داخلها خلال فترة الدراسة، وتتيح التحكم في تدفق الهواء. ويُبشّر استخدام أنظمة الطاقة الحرارية الأرضية في المباني بالجزائر بمستقبل واعد نظرًا لتوافر هذه الموارد وطبيعتها الطبيعية.

الكلمات المفتاحية: مبادل حراري بين الهواء والأرض؛ تجريبي؛ درجة الحرارة؛ حظيرة دواجن؛ كفاءة حرارية.

Résumé :

En Algérie, les recherches sur les technologies d'échangeurs de chaleur air-sol (GAHE), qui stockent la chaleur dans le sol, sont actuellement insuffisantes. En permettant à l'air de traverser un échangeur de chaleur, le sol sert de milieu de stockage de chaleur ou de fraîcheur. Une étude pilote détaillée a été menée pour étudier les performances thermiques des GAHE dans les élevages avicoles. Le modèle étudié a été conçu en forme de U, avec 15 tuyaux en PVC et un ventilateur d'extraction à son extrémité. L'étude a utilisé une approche comparative pour évaluer la qualité de l'air à l'intérieur d'élevages avicoles hybrides et conventionnels. Les résultats ont montré que la température de l'air à la sortie de l'échangeur de chaleur restait stable, entre 24 et 27 °C, quelle que soit la température ambiante, tandis que l'efficacité moyenne des GAHE a été estimée entre 91.13

% et 92.56 %. Par ailleurs, la température produite par la combustion dans les élevages conventionnels était proche de celle produite par l'échangeur de chaleur. GAHE maintiennent une humidité relative modérée grâce au mouvement et à la circulation des molécules d'air générés par le ventilateur. Les échangeurs de chaleur air-sol contribuent positivement à la ventilation des poulaillers, en renouvelant l'air ambiant pendant la durée de l'étude et en permettant un contrôle précis du flux d'air. L'utilisation de systèmes géothermiques dans le bâtiment en Algérie présente un avenir prometteur grâce à l'abondance et au caractère naturel de cette ressource.

Mots-clés : échangeur air-sol ; expérimentation ; température ; poulailler ; rendement thermique.

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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.

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Nomenclature

EGS	Enhanced Geothermal System
WHO	World Health Organization
RH	Relative humidity, %
GAHE	Ground Air Heat Exchanger
EAHE	Earth to Air Heat Exchanger
EATHE	Earth Air Tunnel Heat Exchanger
GHP	Geothermal heat pump
GSHP	Ground Source Heat Pump
T	Temperature , ℃
η	Efficiency
EAHE	Earth-Air heat Exchanger
HVAC	Heating, Ventilation, and Air Conditioning
RETs	Renewable Energy Technologies
NZEB	Net Zero Energy Building
NZEPB	Net Zero Energy Poultry Building
HPH	Hybrid Poultry House
TPH	Traditional Poultry House
CO_2	Dioxide Carbon
WE	Wet Soil
DE	Dry Soil
PHE	Polyethylene Heat Exchanger
PHT	PHotovoltaic/Thermal

LCC	Life Cycle Cost
GHEi	Geothermal Heat Exchanger inlet
GHEo	Geothermal Heat Exchanger outlet
HWAHE	Horizontal Water-to-Air Heat Exchanger
CBGHE	Conic Basket Ground Heat Exchanger

General introduction

The surge in energy consumption and the environmental repercussions of conventional energy sources have spurred researchers to delve into sustainable and renewable energy solutions for agricultural structures. Among these, geothermal energy has emerged as a focal point due to its continuous nature and its capacity to maintain stable thermal conditions with minimal energy usage. Geothermal energy stands out among renewable technologies for its ability to generate base load energy with impressive efficiency. Unlike solar panels that halt energy production at night or wind turbines that are inactive during lulls, geothermal power plants harness steady heat from underground reserves that remain at a constant temperature, unaffected by surface weather changes. This steadfastness grants geothermal energy a capacity factor typically surpassing 90% [1].

In the realm of poultry production, ensuring suitable indoor environmental conditions is vital for fostering animal health, enhancing productivity, and providing thermal comfort. Elements like temperature, humidity, and air quality significantly impact poultry growth and welfare, particularly in semi-arid regions like the region of El Oued, known for its challenging climatic conditions[2].

Hybrid poultry facilities demand efficient ventilation and heating systems to sustain appropriate indoor conditions throughout the year. In this regard, geothermal heat exchangers offer an effective solution for minimizing energy consumption and enhancing indoor air quality [3, 4]. These systems exploit the relatively stable temperature below the ground to condition incoming air before it enters the facility. Consequently, geothermal systems boost thermal efficiency, lower operational costs, and support sustainable agricultural progress.

This experimental study seeks to assess the performance of a geothermal heat exchanger integrated into a hybrid poultry housing system and evaluate its effects on indoor environmental conditions. It further compares this performance with that of conventional poultry facilities. This study focuses on the thermal aspect and the system's ability to reduce heat stress in poultry by reviewing temperature and relative humidity values. However, it does not neglect the environmental aspect, as concentrations of gas emissions inside the poultry house, such as CO and CO2.

The work is structured into three chapters. Chapter I explores recent advancements in geothermal energy technology, starting with a historical background, identifying primary resources and types, and examining current global trends with a focus on Algeria. Chapter II reviews existing literature on previous efforts to integrate geothermal and other renewable energy technologies into poultry facilities and agricultural structures. Chapter III outlines the experimental study, detailing the study area, system installation, measurement techniques, and procedures. It also discusses results relating to indoor air quality parameters such as temperature, humidity, and dew point, along with assessing the geothermal heat exchanger's thermal efficiency.

Overall, this research aims to underscore the significance of geothermal energy systems as viable alternatives promoting sustainable and energy-efficient agricultural methodologies while enhancing the environmental and energy performance of hybrid poultry farms.

Chapter I: State of art: Geothermal Energy

I.1. Introduction

Energy availability stands as one of the fundamental drivers of a society's progress. a significant portion of today's energy is derived from burning organic fuels to generate useful work or power. However, the supply of these fuels is limited due to the growing global demand for primary energy and the urgent need to accelerate the decarbonization process. As a result, transitioning from conventional fuel-based power systems to renewable energy technologies is becoming increasingly vital not only for ecological preservation but also for fostering the growth and development of sustainable energy resources[5] .

Geothermal energy is one of the most remote sources of renewable energy, and it is often regarded as a dependable and self-sufficient source. Because weather circumstances cannot affect this approach, it is often characterized by great reliability, which is a significant benefit, especially in the generation of energy[6] .

The development of green, clean, and renewable energy has become a top goal. Governments around the world have implemented policies to encourage a green and low-carbon economy. China's "14th Five-Year Plan" for a Modern Energy System aims to raise non-fossil fuel use to 25% by 2030[7] .

Recently, renewable energy sources, including solar, wind, hydrogen, tidal, biomass, and geothermal, have seen great advancement due to their environmental benefits and sustainability[8] .

I.2. Brief geothermal history

Our predecessors must have assumed that areas of the Earth's interior were heated due to the existence of volcanoes, hot springs, and other thermal phenomena. But humanity didn't realize that the Earth's temperature rose with depth until the sixteenth and seventeenth centuries, when the first mines were dug several hundred meters below the surface.[9]

The first measurements by thermometer were probably performed in 1740, in a mine near Belfort, in France[10]. Heat balance and the Earth's thermal history were not fully understood until the twentieth century, when the significance of radiogenic heat was discovered. By 1870, however, contemporary scientific methods were being employed to examine the Earth's thermal regime. In actuality, the heat continuously produced by the decay of the long-lived radioactive isotopes of uranium (U238, U235), thorium (Th232), and potassium (K40) that are present in the Earth must be considered in all contemporary thermal models of the planet.[11]

In addition to heat generated by radioactive decay, other possible sources of Earth's internal heat include the primordial energy left over from planetary formation, though their exact contributions remain uncertain. It wasn't until the 1980s that realistic models addressing these mechanisms became available. These studies revealed that the heat produced by radioactive decay inside the Earth does not fully match the heat being lost to space, indicating that our planet is gradually cooling over time. To provide an overview of the phenomenon and its scale, we refer to the heat balance analysis by Stacey and Loper (1988). According to their estimation, the Earth releases a total heat flow of approximately 42×10^{12} W through conduction, convection, and radiation. Breaking this down further, 8×10^{12} W originates from the Earth's crust, which, despite accounting for only 2% of the planet's total volume, is abundant in radioactive isotopes. The mantle, comprising 82% of the Earth's volume, contributes 32.3×10^{12} W. Meanwhile, the core, which represents 16% of the Earth's volume and contains no radioactive isotopes, accounts for just 1.7×10^{12} W. (Refer to Fig I.1 for an illustration of Earth's internal structure.) Notably, the radiogenic heat generated in the mantle is estimated at 22×10^{12} W, indicating that the cooling rate in this region amounts to 10.3×10^{12} W. [9]

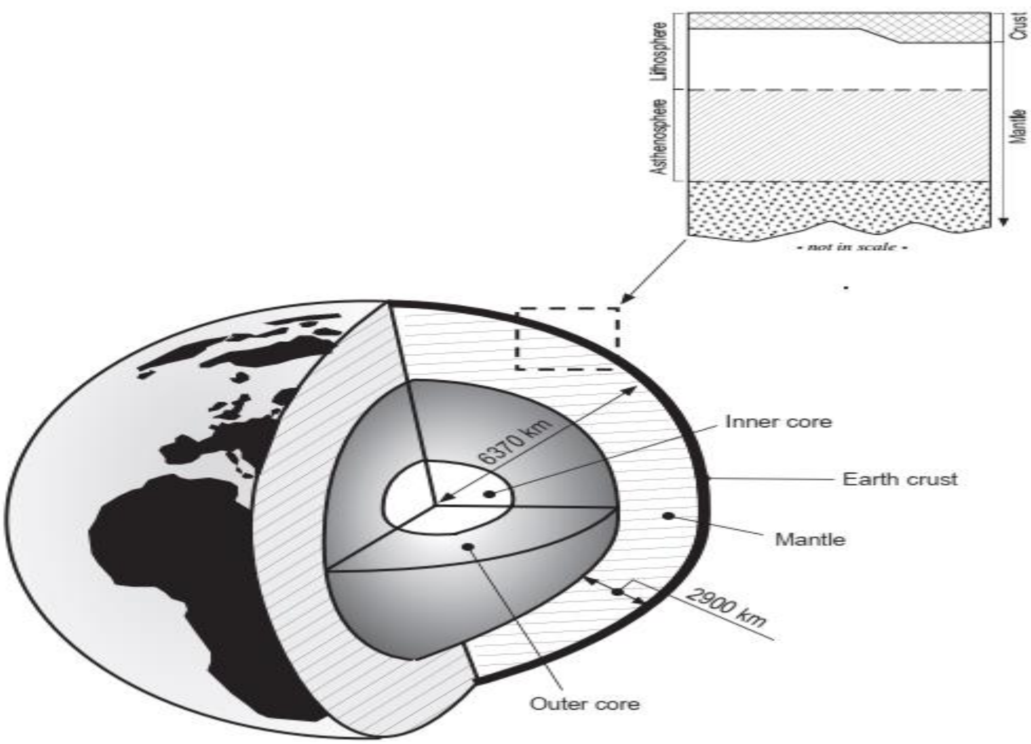


Fig I.1: The Earth's crust, mantle and core. Top right: a section through the crust and the uppermost mantle[9]

I.3. Geothermal energy

Geothermal energy is one kind of renewable energy that is produced within the earth and can be used directly for heating or transformed into electrical power. One benefit of geothermal energy as opposed to renewable energy sources is that it is available year-long (whereas solar and wind energy is more prevalent variability and intermittence) and can be found all over the world. But, for electricity generation, medium- to resources with high temperatures, which are typically near active volcanoes. regions, are required.[12]

Shallow geothermal energy, hydrothermal geothermal energy, and dry-heat rock geothermal energy are the three types of geothermal energy based on their thermal heat storage properties.[13, 14]

Shallow geothermal energy occurs at depths of less than 200 m and temperatures ranging from 25°C to 90°C. This form of energy has multiple applications, including washing, cooking, and greenhouse growing, and breeding. [15]. Medium-depth and ultra-deep geothermal energy, where temperatures range from 90 °C to 150 °C and exceed 150 °C respectively, occur at depths ranging from 200 m to 3000 m and beyond 3000 m. [16]. This sort of geothermal energy is used for building heating, cooling, and electricity generation.

I.4. Geothermal energy resources

I.4.1 Geothermal resources potential energy

The decay of the naturally radioactive isotopes uranium, thorium, and potassium is the main source of geothermal energy, which is derived from the Earth's natural heat. The Earth's surface heat flux averages 82 mW/m^2 due to internal heat, or roughly 42 million megawatts of total heat. The Earth's overall heat content is about 12.6 x 1024 MJ, while the crust's heat content is about 5.4 x 1021 MJ.[17]. This huge number can be compared to the world electricity generation in 2007 of 7.1 x 1013 MJ [18]. The Earth's thermal energy is vast, yet only a small portion of it can be harnessed. To date, its utilization has mostly been restricted to regions where geological conditions allow a medium, such as water in either liquid or vapor form, to transport heat from deep underground hot zones to the surface or near it, thereby forming geothermal resources.

The Earth's temperature increases with depth at an average rate of 25–30°C per kilometre beyond the surface's ambient temperature, a phenomenon known as the geothermal gradient. At a depth of 10 km, this conductive gradient suggests temperatures exceeding 300°C. However, most geothermal exploration and energy utilization focus on areas with higher gradients, as these allow for shallower and less expensive drilling operations. Such shallow geothermal resources often arise from specific geological conditions, including:

1) the intrusion of molten rock (magma) from deeper layers, which brings substantial heat upwards;

2) elevated surface heat flow resulting from a thinner crust and steeper temperature gradients;

3) Groundwater ascending after circulating several kilometres below ground, absorbing heat from the natural temperature gradient;
4) Thermal insulation of deep rocks by thick deposits of low-thermal-conductivity formations such as shale;
5) localized heating of shallow rocks caused by the decay of radioactive elements, potentially intensified by thermal blanketing effects[19] .

At the base of the continental crust, temperatures are estimated to range between 200°C and 1000°C. At the Earth's core, these temperatures are believed to reach approximately 3500°C to 4500°C. Heat from the Earth's interior is primarily transferred towards the surface through conduction. Geothermal production wells typically reach depths exceeding 2 km, though they rarely extend beyond 3 km. Based on the average geothermal gradient, a well drilled to a depth of 1 km in dry rock formations would generally have a bottom temperature around 40 to 45°C in many regions of the world, assuming a mean annual air temperature of 15°C. A well extending to 3 km would have an estimated bottom temperature of 90 to 100°C [20].

I.4.2 Geothermal Resource Types

Based on White and Williams (1975)[21], geothermal resources are typically categorized as indicated in Table I.1. The average yearly ambient temperature of these geothermal resources ranges from around 20˚C to more than 300˚C. Although power has recently been produced at Chena Hot Springs Resort in Alaska with a 74˚C geothermal resource, resources over 150˚C are typically employed for electric power generation [22].
In direct-use projects, resources below 150˚C are often utilized for heating and cooling. Geothermal (ground-source) heat pumps can be utilized for both heating and cooling at ambient temperatures between 5 and 30˚C [23].

Table I.1: Geothermal Resource Types[23]

Resource Type	Temperature Range (˚C)
Convective hydrothermal resources	
Vapor dominated	240˚
Hot-water dominated	20 to 350˚+
Other hydrothermal resources	
Sedimentary basin	20 to 150˚

Geopressured	90 to 200˚
Radiogenic	30 to 150˚
Hot rock resources	
Solidified (hot dry rock)	90 to 650˚
Part still molten (magma)	>600˚

I.4.4.1 Convective hydrothermal resources:

Convective hydrothermal resources may be discovered when convective circulation of naturally existing hot water or steam carries the Earth's heat upward. Temperatures between 500 and 1000˚C from molten intrusions of freshly cemented rocks underlie several high-temperature convective hydrothermal resources. The deep-water circulation along cracks is the cause of the lower temperature resources.[24]

I.4.4.2 Hot dry rock resources

Hot dry rock resources are described as heat that is held in rocks within ten kilometres of the surface, from which steam or naturally occurring hot water cannot profitably extract energy. These hot rocks contain minimal water and little to no interconnected permeability because they have few pores or cracks. New experimental technologies are being attempted to extract the heat, such as hydraulic fracturing under pressure, which is followed by cold water running down one well and generating hot water from a second well in a closed system [24].

I.4.3 Exploration for geothermal resources

The first prerequisite before beginning the extraction process is the search for possible geothermal reservoirs. Although there are several types of geothermal resources, the ideal conventional geothermal system requires water, heat, and permeability, as seen in Fig I.2. There is a constant outward flow of heat radiating from the earth's core. The heat usually remains below the earth's crust, searing nearby rock and water to temperatures that can reach several hundred degrees Celsius. On rare occasions, the heat rises to the surface as lava or magma. When hot water or steam is trapped in porous and permeable rocks behind an impermeable layer after being heated by the earth's heat, a geothermal aquifer may develop. The bulk of hot geothermal water is confined in fissures and porous rock under the surface, where it may emerge as hot springs. This natural method of storing hot water is called a geothermal reservoir [25]

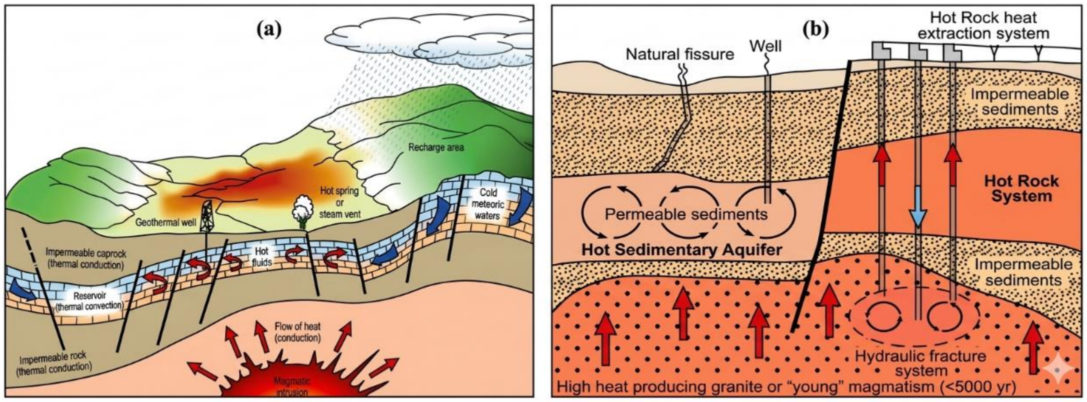


Fig I.2 (a) Schematic representation of an ideal geothermal system and (b) Hot rock and hot sedimentary aquifer system[25]

The production of geothermal energy is now confined to a small range of distances from the Earth's surface due to financial and technological limitations. Less than five kilometres have been dug into geothermal reservoirs thus far. The methodology for investigating geothermal sources should be developed similarly to any other natural source. Following the identification of a certain geothermal zone, several research techniques are used to identify possible geothermal locations and choose suitable targets for fluid production. In addition, it is necessary to compute variables like temperature, reservoir capacity, and permeability at depth. The chemical composition of the fluid that will be produced ideally requires the estimate [26]

here are a variety of exploring approaches accessible to get this diverse information:

- Surface manifestation inventory and survey
- Geological and hydrogeological survey
- Geo-chemical survey
- Geo-physical survey[27]

I.4.4 Extraction of geothermal energy

A geothermal gradient is nearly always the first indicator that the underlying rocks in a certain area are hotter than the mean value. A magma intruding in the range of a few kilometres of the crust constituting a temperature reading of 600–1000◦C could be the localized heat source. Despite this, geothermal fields can form in locations that haven't been affected by recent super-facial magmatic intrusions [28]

Certain conditions, such as continental crust thinning, which causes the crust-mantle boundary to up-well and raise temperatures at shallower depths, may be responsible for the abnormally elevated heat flux. But a thermal anomaly is not enough for a geothermal resource to be sustainable. Additionally, a reservoir or a sizable body of porous rock at a specific depth that can be reached by drilling is required [29].

Reservoirs, recharging areas, and canals that let cold subsurface water into the reservoir are examples of hydrothermal structures. Geothermally accessible energy may be exploited to produce power at a low cost by using magmatic deposits high enough in the crust to induce groundwater convection. They are more prevalent in places that are susceptible to metamorphism and structural weakness. The most prevalent hydrothermal systems are water-oriented and vapor-oriented [30]. Both the conventional and advanced techniques of the geothermal heat extraction process must be explained in order as it is widely known that the first step in using the heat for various applications should be choosing its extraction mechanism.

I.4.4.1 Conventional extraction method

There are several technological steps involved in the conventional geothermal heat extraction process. The three most important procedures that must be carried out in order to extract the useful quantity of geothermal heat from a possible location or reservoir are drilling, extraction, and fluid distribution. Fig I.3 illustrates the basic procedures that are used for these procedures [31].

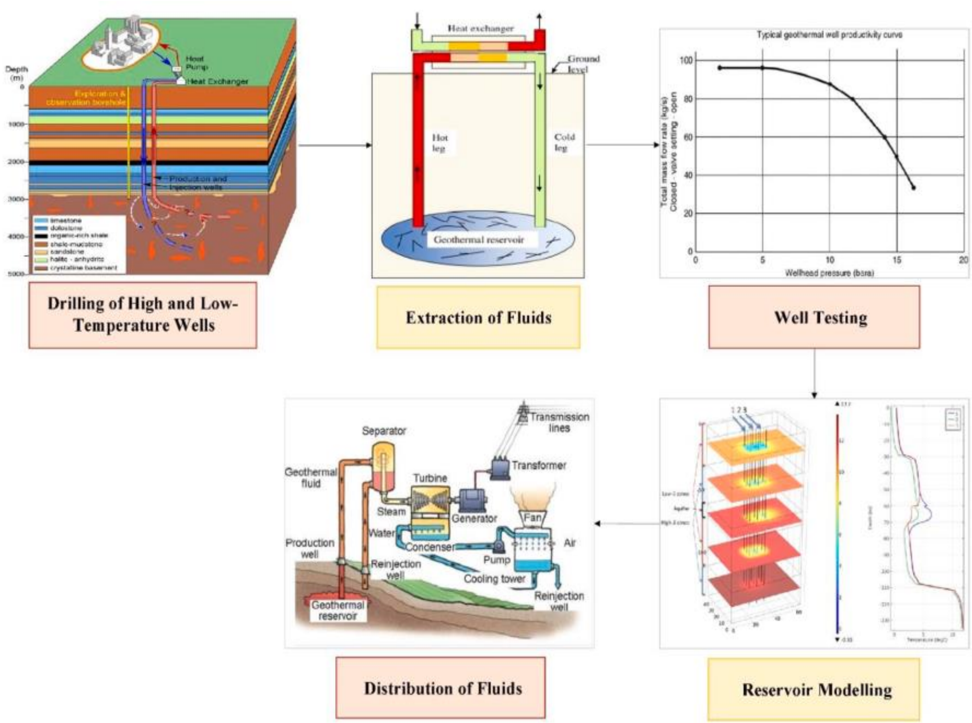


Fig I.3 Steps for Conventional extraction method of Geothermal Energy.

I.4.4.1.1 Drilling of high-temperature wells (>150◦C)

Drilling and finishing a well are the most important steps in the construction of a geothermal project. Drilling for geothermally accessible fluids follows the same procedure as rotary drilling for oil and gas. The rock in geothermal wells is often harder, metamorphic, or igneous than sedimentary, and the high temperatures have an impact on the drill string and casing design, cementing techniques, and circulation system.[32]

When the region directly above a drilling site is inaccessible, directional drilling techniques are used; occasionally, a well pad is made due to economic or environmental considerations. The angle is established and maintained using a downhole turbine drill. Directionally drilled wells are around 25% more expensive than vertically drilled wells because to the slower penetration rates [33]

I.4.4.1.2 Drilling of low-temperature wells (<150◦C)

Drilling and casing a low-temperature well is perhaps the costliest procedure in geothermal projects for non-electrical use. The cost of the drilling mechanism is quite high, and costs are rising at an exponential rate. The price of the wells increases exponentially with depth. Due to the high cost of drilling, many geothermal deposits based on low temperatures will not be economically feasible to produce. The real cost of drilling is increased by the costs associated with site acquisition and geological investigations [34]

Drilling into geothermal reservoirs with low temperatures involves similar technologies that are usually used for ground-level water reserves. When drilling into these reservoirs, the cost is the most important consideration, and low-temperature wells deeper than 2 km are often not considered economically viable [33]

I.4.4.1.3 Extraction of fluids

Numerous factors affect the flow rate and functionality of a geothermal reservoir. The amount and kind of fluids in the reservoir, the recharge rate, the porosity, the design of pipelines and drilling infrastructures, and the calibre of finishing equipment used are only a few of these factors. Fluids can exist at the interface as liquid, vapor, or a combination of both, depending on the characteristics of the particular reservoir. It can also concurrently include other dispersed substances and solid particles. The kinds of equipment needed to remove fluids from a particular reservoir will thus depend on the enthalpy-pressure characteristics of the fluid, particularly the amount of salt. For low-temperature fluids of importance in nonelectrical applications, the liquid phase[29].

I.4.4.1.4 Distribution of fluids

Production-integrating systems move fluid that has been recovered from reserves to various utilization structures or energy stations. Steam with very little moisture is produced by vapor-oriented reservoirs and sent right away to the energy plants. The fluids from the reserves are transported into the separators in water-oriented aquifers that produce both water and steam. A small fraction of fluids (17–22%) is allowed by the separator to flash into steam, which is subsequently transferred to the power stations. The surplus waste water and condensates are normally pumped back into the wells for reinjection. Non-electrical (direct) geothermal energy applications require a hot water distribution network. The network is made up of a series of pipes that differ in size based on the flow rates of fluids that pass through the variable branches. Pumps, expansion joints, pumps, valves, meters, and controllers are also required for the network's reliable operation. To minimize excessive heat loss and a temperature reduction in the fluid, the system is usually thermally insulated [29]

I.4.4.2 Advanced or engineered extraction methods

I.4.4.2.1 Enhanced geothermal systems (EGS)

By making it possible to collect heat from dry, impermeable rock formations that lack adequate natural fluid or permeability, Enhanced Geothermal Systems (EGS) have the potential to significantly increase the availability of geothermal energy. This method uses hydraulic fracturing and other stimulation techniques to increase the permeability and absorption of hot, dry rocks in geothermal locations by injecting highly pressured water. Water passes through fissures, forming man-made reservoirs, and returns to the surface when the rocks heat it enough to produce power [35]

I.4.4.2.2 Hybrid geothermal systems

To improve efficiency, dependability, and total energy production, hybrid geothermal systems combine geothermal energy with other renewable energy sources like solar or wind. These systems employ a variety of energy sources to get beyond the drawbacks and restrictions of each distinct kind of technology [35]. Combining solar and geothermal thermal energy is one hybrid system that is frequently used. In this setup, solar collectors raise the temperature of geothermal fluids prior to their entry into the power generating cycle [36]. It is possible to increase the efficiency of such a power plant, particularly in situations where geothermal resources are insufficient to attain ideal performance. Geothermal power facilities may increase their production and overall efficiency by up to 30% using hybrid geothermal-solar systems [37].

I.4.4.2.3 Emerging techniques and future directions

A number of cutting-edge methods and creative strategies are being investigated to further improve the viability and efficiency of geothermal energy extraction as the industry develops. Using cutting-edge drilling techniques like laser aided drilling and spallation drilling, which are intended to reduce the expenses and technical challenges related to reaching deep geothermal resources, is one such strategy. These cutting-edge drilling techniques have the potential to reduce the cost of building geothermal wells by 30% to 50%, increasing the economic viability of deep geothermal resources [38].

I.5. Utilization of geothermal energy

Heat from the earth's molten core permeates surrounding rocks and eventually spreads to subterranean water reservoirs through convection. The steam or water heated by geothermal energy may be accessed and directed toward various purposes using a variety of methods.

The chemical and thermodynamic characteristics of geothermal fluid are very important for how it is used. Depending on the enthalpy, geothermal fluid may often be used either directly or indirectly. High-temperature geothermal resources are primarily utilized for energy generation, whereas low to medium-temperature ones are especially well-suited for non-electric (direct) uses, as shown in Fig I.4

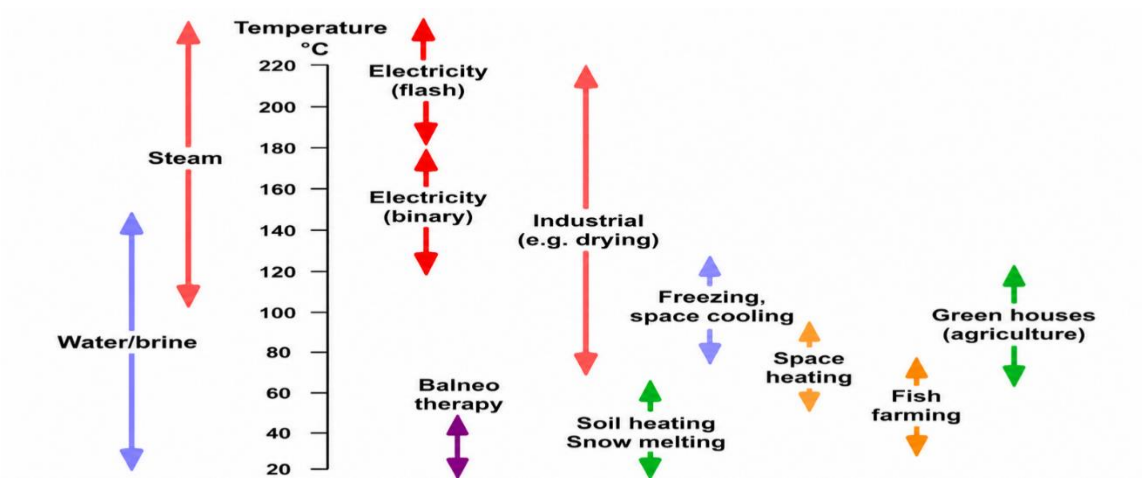


Fig I.4 Geothermal energy applications depending on temperature of the geothermal fluid.

I.5.1 Geothermal globe direct use

Direct use of geothermal energy uses heat energy for a variety of purposes without the need of any other medium, in contrast to geothermal energy generation, which transforms heat energy into electrical energy. The temperature range in which these applications function is 20°C to 150°C[39] The statistics of the various direct-heat geothermal energy applications that are leading the world are displayed in the Table I.2, with an estimated effective thermal power of 283,580 GWh globally, expanding at a rate of 8.0% annually and a capacity factor of 0.3, 108 (88 were reported) nations currently record direct geothermal energy consumption due to the discovery and development of direct heat applications worldwide [40, 41] **.**The growth rates of installed capacity and annual energy use over the past 30 years are summarized in Fig I.5

Table I.2: Summary of direct-use data worldwide by region and continent, 2019[42]

Region/Continent (#countries/regions)	MWt	TJ/year	GWh/year	Capacity Factor
Africa (11)	198	3,730	1,036	0.597
Americas (17)	23,330	180,414	50,115	0.245
Central America and Caribbean (5)	9	195	54	0.687
North America (4)	22,700	171,510	47,642	0.24
South America (8)	621	8,709	2,419	0.445
Asia (18)	49,079	545,019	151,394	0.352
Commonwealth of Independent States (5)	2,121	15,907	4,419	0.238
Europe (34)	32,386	264,843	73,568	0.259
Central and Eastern Europe (17)	3,439	28,098	7,805	0.259
Western and Northern Europe (17)	28,947	236,745	65,762	0.259
Oceania (3)	613	10,974	3,048	0.568
Total (88)	107,727	1,020,887	283,580	0.300

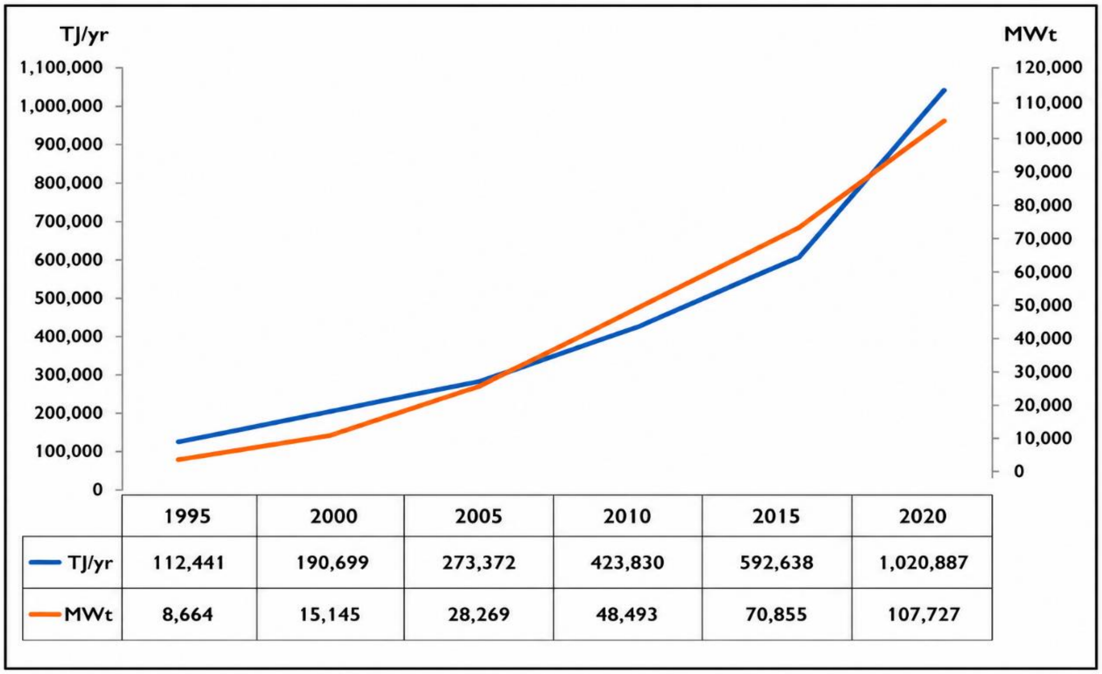


Fig I.5 the growth rates in installed capacity and annual energy consumption between 1995 and 2020 [43]

I.5.2 Categories of direct utilization

The distribution of energy usage across different applications is illustrated in Fig I.6 as a bar chart. It highlights the top six energy uses during 1995-2020 which include geothermal heat pumps, bathing and swimming, space heating, greenhouse heating, aquaculture and pond heating, and industrial applications.

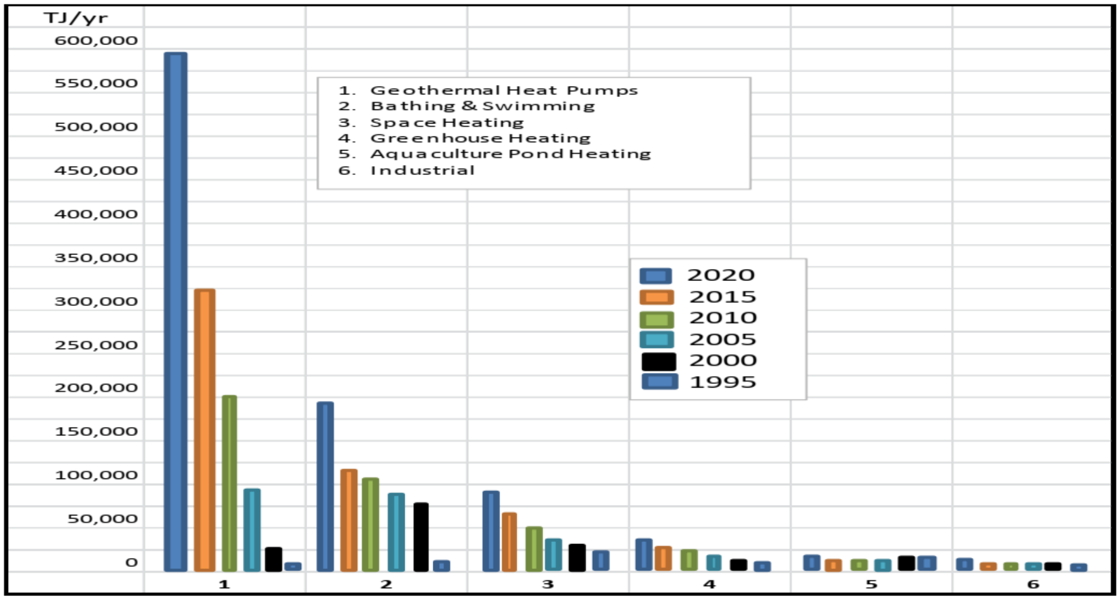


Fig I.6 Comparison of worldwide direct-use of geothermal energy in TJ/yr[40]

The graph indicates that the growing awareness and widespread adoption of geothermal heat pumps have been the most significant factors driving the ongoing advancement of geothermal energy worldwide utilization.

I.5.3 Geothermal energy utilization in Algeria

Algeria possesses considerable geothermal potential. While most of its geothermal resources are characterized by relatively low enthalpy, making them unsuitable for electricity generation, they remain well-suited for direct heating applications. Algeria stands as the leading country in Africa for the direct utilization of geothermal energy. As highlighted in Table I.3, the country boasts an installed thermal power capacity of 54.64 MWt along with an annual energy usage of 1699.65 TJ/year [44].

Table I.3 The installed direct use geothermal capacity in Africa.[44]

Country	MWt	TJ/year
Algeria	54.64	1699.65
Egypt	6.80	88.00
Ethiopia	2.20	41.60
Kenya	22.40	182.62
Madagascar	2.81	75.59
Morocco	5.00	50.00

South Africa	2.30	37.00
Tunisia	43.80	364.00
Total	140	2538

In Algeria, the primary application of geothermal energy is in balneology, accounting for approximately 82% (44.37 MWt) of the total geothermal energy usage, which stands at 54.64 MWt. The remaining 18% (10.28 MWt) is allocated to other uses, including space heating, heat pumps, and fish farming, as illustrated in Fig I.7[44, 45].

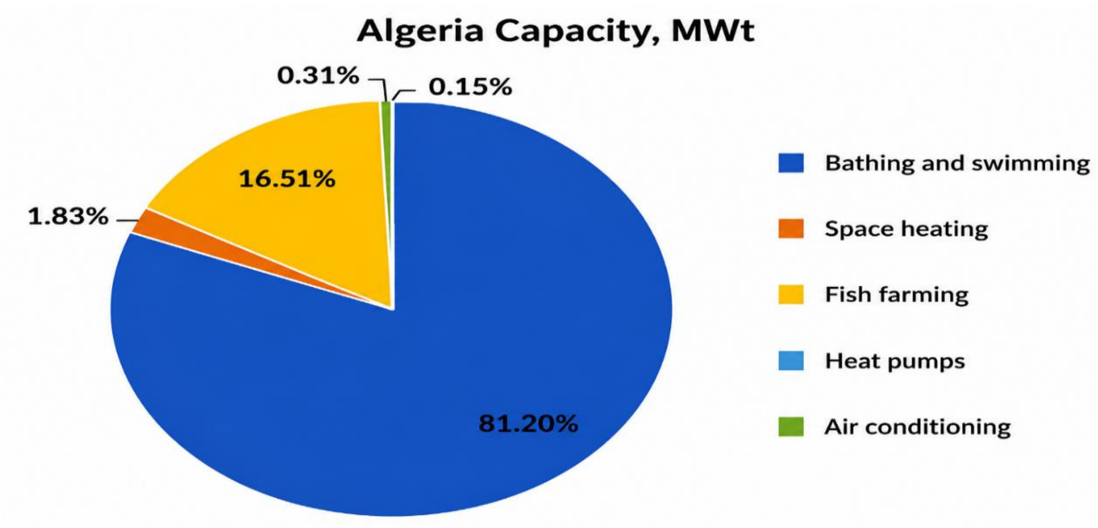


Fig I.7 Distribution of total installed capacity of geothermal energy (MWt) in Algeria[44].

I.5.4 Current applications in practice

The majority of geothermal resources in Algeria, as previously noted, are of the low-enthalpy type. Table I.4 outlines the current uses of these geothermal resources as well as potential future applications for the country's main geothermal sites. From the table, it is evident that the temperature of geothermal water in Algeria ranges between 20°C and 98°C. This temperature range highlights the viability of geothermal energy for a variety of applications, including space heating, aquaculture ponds, raceway and greenhouse heating, agricultural crop drying, space cooling, snow melting, balneology, thermal tourism, electricity generation, and industrial process heating.[45-47].

Table I.4 The current uses of geothermal resources in Algeria[45-48]

Geothermal source	T (°C)	Applications in practice	Potential utilization opportunities
Meskhoutine	98	Balneotherapy, space heating	Balneotherapy, space heating, greenhouse heating, drying, industrial, electricity (binary) and other applications
Bouhanifia	68	Balneotherapy, space heating	Balneotherapy, space and greenhouse heating, drying, industrial, fish farming, snow melting
Righa	68	Balneotherapy	Balneotherapy, space and greenhouse heating, drying, industrial, fish farming, snow melting
Bouhadjar	65	Balneotherapy	Balneotherapy, space and greenhouse heating, drying, industrial, fish farming, snow melting
Guergour	44	Balneotherapy	Balneotherapy, space and greenhouse heating, fish farming, snow melting
Elssalhine	43	Balneotherapy	Balneotherapy and greenhouse heating, fish farming
Boughrara	37	Balneotherapy	Balneotherapy, greenhouse heating, fish farming, snow melting
Chiguer	35	Balneotherapy	Balneotherapy, greenhouse heating, fish farming, snow melting
Ain Skhouna	31	Balneotherapy, fish farming	Balneotherapy, greenhouse heating, fish farming
Albian aquifer (Sahara area)	20–60	Balneotherapy, fish farming, greenhouse heating	Balneotherapy, space and greenhouse heating, drying, industrial, fish farming and other applications

I.5.5 Previous studies in Algeria

Within Algerian universities, a number of theoretical investigations have been carried out to explore the potential of geothermal source heat pumps (GSHPs). Nonetheless, experimental research in this field remains relatively scarce. To date, only six experimental geothermal heat exchangers have been installed, as detailed in Table I.5.

Table I.5 Previous university experimental studies in Algeria[49-54]

Location	Year	System technical specification
Biskra	2010	Earth to air horizontal heat exchanger; pipe length: 60 m; material: PVC; burial depth: 3 m; pipe diameter: 0.11 m.
Oran	2013	Earth to air horizontal heat exchanger; pipe length: 120 m; material: zinc; burial depth: 3 m; pipe diameter: 0.12 m.
Oran	2014	Water to soil heat exchanger coupled with a cooling floor; the system consists of two galvanized steel water tanks with a volume of 2 m^3 each and located at a 2 m shallow depth.

Oran	2015	Two earth to air horizontal heat exchangers, first one with zinc material and second one with PVC material; both exchangers have the same configuration; pipe length: 20 m; burial depth: 2 m; pipe diameter: 0.12 m.
El Oued	2017	Water to air helical heat exchanger; pipe length: 30 m; burial depth: from 2 to 5 m.
Bechar	2018	Earth to air heat exchanger; pipe length: 66 m; material: PVC; burial depth: 1.5 m; pipe diameter: 0.11 m.

I.6. Conclusion

According to the World Energy Council, energy sustainability hinges on three core pillars: energy security, energy equity (defined by accessibility and affordability), and environmental sustainability. The future growth of geothermal energy investments will largely depend on how effectively this technology and its regulatory framework align with these objectives.

That said, the long-term viability of the geothermal energy sector in the 21st century demands substantial innovation. The existing cost structure for steam wells and drilling operations is unsustainable. Challenges related to cost efficiency, safety, and occupational health are driving a shrinking workforce on drilling platforms.

In Algeria, geothermal energy remains an underutilized resource due to various factors. The country's geothermal technologies lag significantly behind those employed in more developed nations. Additionally, inefficient resource development results in subpar performance across the sector. Direct applications of geothermal energy are hindered by a critical shortage of appropriate equipment, much of which is outdated, inefficient, or environmentally unsound. These challenges highlight that Algeria's technological progress in this field has yet to meet global standards.

Chapter II: Literature review: Poultry Houses

II.1. Introduction

The poultry industry ranks as one of the most energy-demanding sectors in agriculture. Energy plays a key role in maintaining the internal conditions of farms, encompassing heating, cooling, ventilation, lighting, feed processing and distribution, as well as waste management. Given the high sensitivity of poultry to environmental factors, heating and cooling dominate energy consumption, especially in broiler production. This segment alone requires around 75.5% of all electricity and a substantial 96.3% of thermal energy to sustain ideal growth and production conditions [55].

There are two key priorities emerge for decision-makers and researchers. The first is to strengthen the resilience of the poultry sector against the volatility of global energy prices and markets, which pose a risk to its economic sustainability. The second is to address the sector's increasing carbon footprint by implementing sustainable practices and environmentally friendly technologies [56]

This part focuses on using the RETs especially earth air heat exchanger to harvest shallow geothermal energy as a sustainable and alternative method of cooling poultry houses. Although its use is still somewhat restricted in Algeria, this low-emission technology offers a workable alternative to traditional air conditioning systems that rely on electricity or fossil fuels.

II.2. Poultry farming

A poultry farm serves as a facility designed for raising domesticated birds. Common poultry species include chickens, turkeys, ducks, and geese, which are predominantly bred for their meat and eggs. Among them, chickens are the most widely raised, serving as a primary source for both products. Chickens bred specifically for meat are known as broilers, while those kept for egg production are referred to as laying hens or layers. Additionally, certain poultry breeds are often raised on hobby farms for purposes such as shows and competitions [57]

II.3. Sustainable poultry farming

Embracing sustainable practices in poultry farming is crucial for securing the industry's resilience and long-term viability. Such methods enhance resource efficiency, minimize environmental impacts, and contribute to the conservation of biodiversity. Refer to fig II.1 [58-60].

Poultry farmers can minimize their carbon footprint by adopting eco-friendly techniques, contributing significantly to climate change.[61] In 2010, advancements in underlying systems and enhanced bird performance played a key role in substantially reducing the environmental impact and resource demands of U.S. poultry meat production when compared to 1965 [62, 63].

Resource-related impacts demonstrated notable reductions, including a 58% decrease in water depletion, a 39% drop in fossil energy usage, and a 72% reduction in agricultural land use per 1000 kg of poultry meat produced. Embracing a paradigm shift toward sustainable poultry farming practices is crucial to tackling these challenges. Such practices not only enhance poultry welfare but also result in healthier birds and improved product quality[60].

Fig II.1 Framework of sustainable poultry production.

II.4. Critical factors in poultry house buildings

II.4.1.Poultry Thermoregulation Mechanism

Poultry are highly sensitive to their surrounding environment and possess distinct mechanisms to adapt to changes, ensuring their body temperature remains within the optimal range of 40 to 41 °C [64]. They utilize various mechanisms to regulate and release heat, such as conduction, convection, radiation, and evaporation through respiration. Additionally, their feathers play a vital role in temperature control by adjusting their positioning. To retain warmth during colder conditions, they puff up their feathers to enhance insulation, while in warmer situations, they flatten them against the body to minimize insulation and facilitate more effective heat dissipation [56].

In situations of heat stress, birds modify their feeding behaviour. When ambient temperatures rise above their comfort range, they decrease food intake to minimize internal metabolic heat production. Conversely, at temperatures below their comfort zone, they increase food consumption to generate additional internal heat [65].

Table II.1. The impacts of heat stress on the growth of birds [26].

Decrease	Increase
Feed intake ↓	Mortality ↑
Egg production ↓	Cannibalism ↑

Egg weight ↓	Immunosuppression ↑
Shell quality ↓	Hatchability ↓
Albumen height ↓	Growth ↓

Birds are influenced by their surroundings, but their physiological responses also affect environmental factors like temperature increases, humidity levels, and gas concentrations. This, in turn, creates a need for greater thermal regulation within buildings, leading to higher energy consumption. By gaining insight into the thermoregulation mechanisms of birds and creating optimal conditions for their care, the industry can take significant steps toward achieving sustainability [56].

II.4.2.Basic Requirements for Poultry Housing Climate Control

Indoor temperature, humidity, gas concentration, and velocity are some of the major variables that impact chicken comfort and health, according to specialized study in the field of poultry production. … While lowering the effect of thermoregulation behaviours on energy consumption and the farm's internal environment, maintaining comfortable circumstances during the breeding phases increases productivity [56].

One of the most important variables influencing the management of poultry buildings is temperature. During the first week, birds cannot regulate their body temperature, requiring a mild environment with temperatures between 33 and 30°C. As their thermoregulation mechanisms develop and feathers grow, these needs diminish. Their optimal temperature range gradually lowers to 26-24°C by the third to fourth week, and by the fifth to sixth week, they thrive in a comfort range of 21-18°C [66-68].

Studies indicate that the ideal relative humidity falls between 60% and 80% during the brooding phase, while in the subsequent growth stages, it is recommended to maintain levels between 50% and 70% [69, 70].

Birds and their waste contribute notably to the emission of harmful gases, including ammonia (NH3), carbon dioxide (CO2), carbon monoxide (CO), and hydrogen sulphide (H2S). These emissions pose risks to birds, humans, and the environment. To mitigate these effects, it is advised that the concentrations of these gases remain below 20 ppm for ammonia, 3000 ppm for carbon dioxide, 10 ppm for carbon monoxide, and 0.5 ppm for hydrogen sulphide [70, 71].

Table II.2 The desirable indoor environment parameters for poultry house

Parameters	Desirable levels
Temperature	
General comfort zone	22–28°C
Up to 1 week	30–32°C
Between 1 and 7 weeks	20–32°C
After 7 weeks	10–27°C
RH	50–70%
Ammonia	<25 ppm

The parameters discussed earlier can be regulated through effective ventilation and continuous renewal of the building's air, which in turn enhances air quality. Research indicates that the ideal air velocity falls within the range of 2 to 3 m/s[72, 73] .

To maintain the necessary internal conditions, farmers follow stringent management practices, utilizing a combination of heating, ventilation, and air conditioning (HVAC) systems.

II.5. Conventional Poultry Building and Management Strategies

II.5.1. Conventional HVAC Systems

Conventional methods for managing a poultry house rely on cooling, heating, and ventilation systems powered by non-renewable energy sources like electricity and fossil fuels. These systems are considered fundamental to the structure, as they play a crucial role in regulating its internal environment.

II.5.1.1. Heating systems

This method utilizes three main types of heating systems: radiators, forced air heaters, and heat exchanger systems

Heating radiators function by emitting radiant energy into the air through electromagnetic waves. When this energy encounters the surface of a bird's body, it is absorbed and transformed into heat. In contrast, forced air heaters operate by using the energy generated during combustion to warm the air, which is then circulated throughout the home via built-in fans. These radiators are typically installed on one side of the house to optimize heat distribution across the entire space[74, 75] .

Alternatively, the operation of a heat exchanger system relies on a counterflow mechanism that transfers heat between outgoing warm air from inside the house and incoming cold air from outside. Warm air exits the house and passes through the heat exchanger, while cold external air is drawn in. Through this process, heat transfer occurs within the exchanger, effectively warming the incoming cold air before it enters the living space[76] .

II.5.1.2. Ventilation systems

When it comes to ventilation systems in poultry houses, industry breeders and specialists typically rely on two primary methods: natural ventilation and mechanical ventilation:

Natural ventilation works by opening the building to the extent needed, enabling outdoor breezes and internal convection currents to move air into and throughout the structure. This is typically done by adjusting side curtains, shutters, or doors. However, this method is only suitable when external conditions closely match the environmental requirements within the poultry house

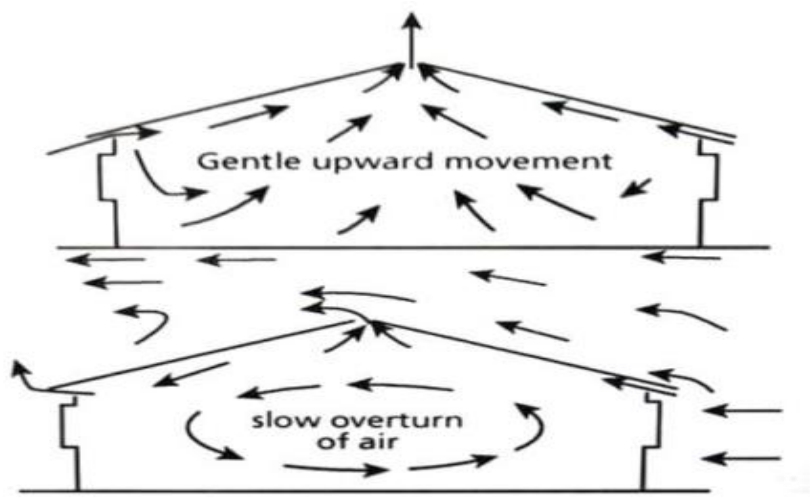


Fig II.2 Natural ventilation in a poultry house[77]

During hot weather, mechanical ventilation is advisable, utilizing fans to circulate air throughout the building at an elevated airflow rate. Among the various types, tunnel ventilation stands out as one of the most effective methods for managing high temperatures. This approach channels substantial volumes of air along the full length of the building, ensuring rapid air exchange. The resulting high-velocity airflow over the birds generates a cooling effect, promoting their comfort and rest. Additionally, this ventilation system allows precise control over both the volume and speed of air entering the building by adjusting the number of fans in operation[77-79] .

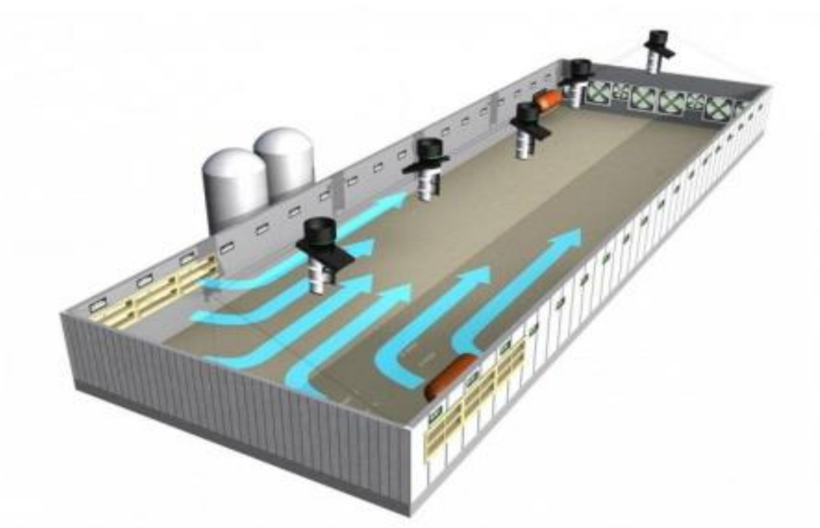
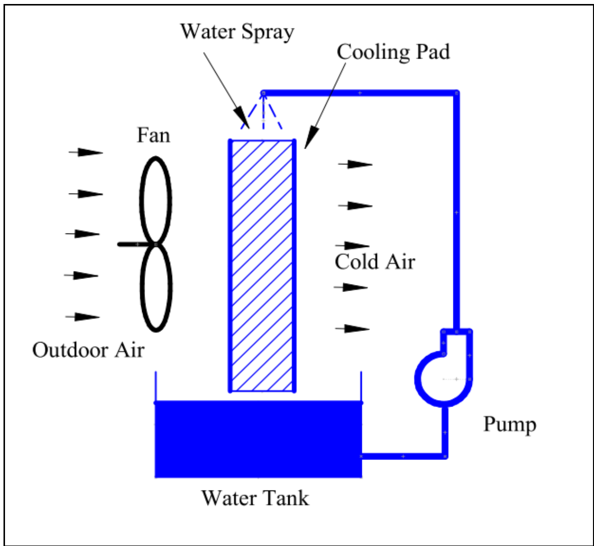


Fig II.3 Tunnel ventilation[77]

II.5.1.3. Evaporative cooling systems

When ventilation alone is inadequate for reducing indoor temperatures, cooling systems such as evaporative cooling are frequently employed. This method works by lowering air temperature through water evaporation, which helps enhance ambient conditions and boosts the efficiency of tunnel ventilation. Evaporative cooling systems are generally categorized into two primary types: water spray and evaporative cooling pads[80] .



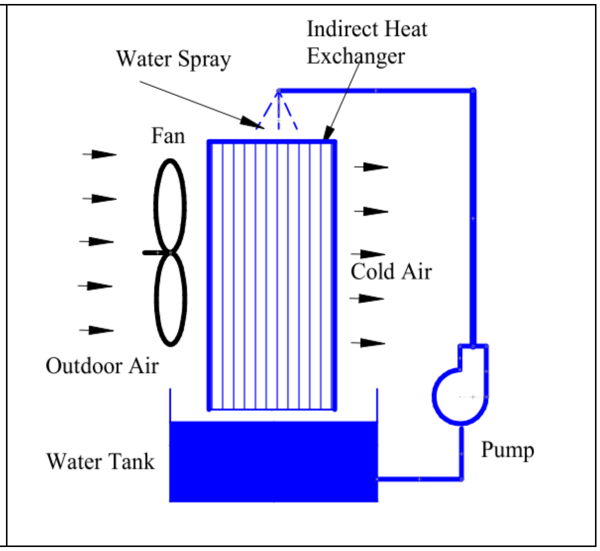


Fig II.4 Direct ECS[80] Fig II.5 Indirect ECS[80]

Water spray systems operate by cooling the incoming air through the evaporation of water droplets, which are dispersed by spray nozzles positioned near the air inlets. In contrast, direct evaporative cooling pad systems utilize mist nozzles to moisten the pads. As air is drawn through these pads into the space, the evaporation of water results in a temperature reduction[75, 81] .

II.5.2.Challenges and limitations of Conventional HVAC Systems.

These HVAC systems, while capable of addressing the majority of the thermal needs in poultry houses, account for the largest share of both thermal and electrical energy consumption in these facilities[82] . This percentage typically falls between 96.3% and 75.5%. Although these values can vary depending on the specific house or climate, they still represent the largest share of total energy consumption in poultry houses, which, in turn, has environmental implications[56] . The performance of these systems can occasionally fall short when compared to their energy consumption. For instance, in desert climates where cooling is essential, these technologies may encounter challenges linked to weather variations, such as sandstorms or air pollution, which can hinder their efficiency or limit their applicability. Similarly, in humid climates, leveraging evaporative cooling becomes problematic due to its diminished cooling effectiveness and elevated indoor humidity levels within poultry houses, potentially resulting in production losses.

Even if some heating systems are effective at producing the right temperatures, they have an impact on interior air quality. For example, forced air heaters that rely on combustion increase humidity and carbon dioxide levels[76] .

Previous challenges have inspired many researchers to explore solutions and strategies aimed at improving both the efficiency and sustainability of this field. One such approach is the concept of Net-Zero Energy strategies.

II.6. Net-Zero-Energy Poultry Buildings Strategies

Analysing the thermal behaviour of poultry buildings is crucial for developing effective and sustainable energy strategies. Gaining insights into how heat is transferred, stored, and distributed within these structures can greatly enhance bird comfort and health, optimize energy use, and minimize environmental impacts. This area of study directly ties into energy conservation in buildings, improving energy efficiency, and utilizing renewable energy sources, making it a key factor in the design and operation of modern poultry farms. Consequently, this section focuses on several core aspects: evaluating the thermal performance of poultry buildings, exploring energy-saving approaches, enhancing energy efficiency, and leveraging renewable energy technologies, as outlined in Fig II.6 **.**

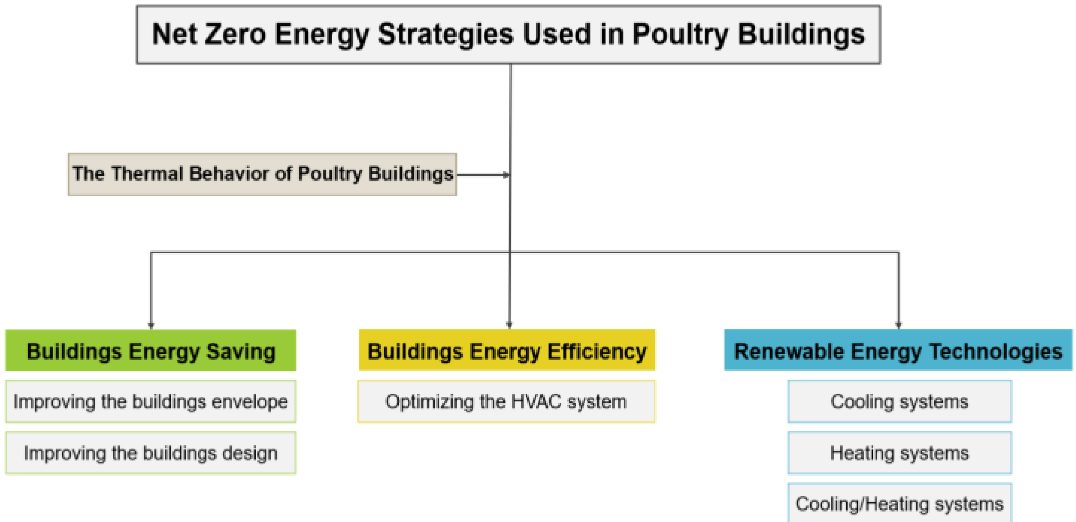


Fig II.6 Net-Zero-Energy Poultry Buildings Strategies[83]

II.6.1.Thermal Behaviour of Poultry Buildings

Analysing thermal behaviour and accurately estimating building thermal loads are essential for assessing energy needs and identifying effective NZEPB strategies. These may include modifying the building or its components, incorporating additional systems, or optimizing existing ones to enhance planning efficiency, reduce production costs, and improve energy management. Thermal loads refer to the amount of energy, whether sensible or latent, that must be added to or removed from an indoor environment by equipment designed to maintain comfortable conditions[84] . Various factors influence the cooling and heating demands in poultry buildings, including:

- The dynamic external and internal conditions[85]
- he building envelope's quality[86]
- ventilation rates[87]
- air infiltration[88]
- the density of birds, and the energy generated from them[84]

II.6.2.Building energy saving

A poultry building serves as the protective environment that shields birds from adverse external climatic conditions, which could negatively affect the performance and productivity of this sector. This protective structure comprises components such as windows, walls, roofs, and floors, which together define the thermodynamic boundaries of the poultry house. These boundaries are crucial for managing the exchange of energy and mass between the internal and external environments.

Research on the thermal behaviour of such buildings highlights the critical role of this envelope in conserving energy, enhancing the efficiency of climate control systems, and minimizing the overall consumption of thermal and electrical energy[89] . As a result, numerous researchers have focused on exploring the most suitable materials, ideal thicknesses, and envelope layers to enhance the thermal insulation of buildings.

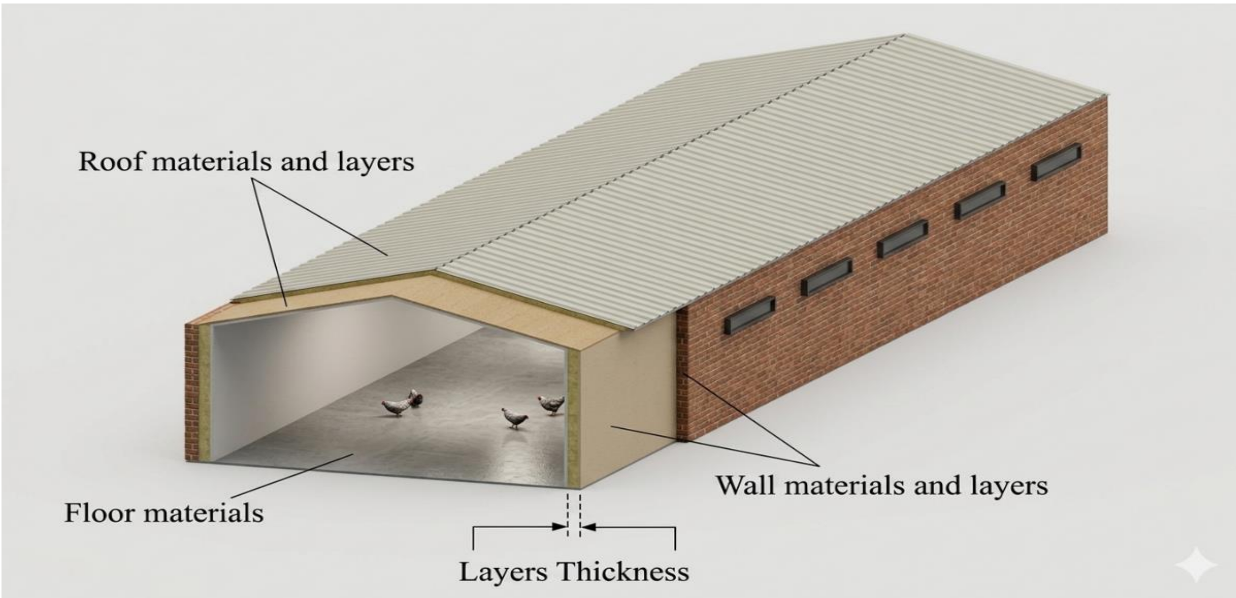


Fig II.7 Parameters included in studying the poultry building envelope [89]

II.6.3.Building Energy Efficiency

Poorly designed or improperly distributed HVAC systems in poultry houses can lead to zones with stagnant air or excessive airflow. Such issues play a major role in causing thermal stress for the birds, which in turn results in decreased productivity and higher energy consumption[90] .To address these challenges, numerous researchers have implemented strategies aimed at enhancing the energy efficiency of such buildings. Their efforts are concentrated on creating innovative designs and optimizing the dimensions of system components to promote balanced air and heat distribution. Additionally, system performance is fine-tuned to adapt to fluctuating indoor and outdoor environmental conditions. The overarching goal of these advancements is to maximize operational efficiency while reducing energy consumption to a minimum[56] .

II.6.4.Renewable Energy Technologies

Numerous studies highlight the critical impact of renewable energy technologies on improving the efficiency and sustainability of poultry houses. In line with this, this section of the study focuses on examining the technologies implemented for cooling, heating, or integrated cooling and heating systems.

II.6.4.1. Cooling Systems

Morshed et al. [91]investigated the thermal performance of earth air heat exchangers (EAHE) in both dry and wet soils. To conduct their study, they constructed two experimental EAHE systems on a poultry farm one operating in dry soil (DE) and the other in wet soil (WE). The results demonstrated that moistening the soil surrounding the EAHE significantly improves heat exchange efficiency. At night, the WE system provided greater air heating compared to the DE system, while during the hottest part of the day, the outlet temperature of the WE system was 1.56°C lower than that of the DE system.

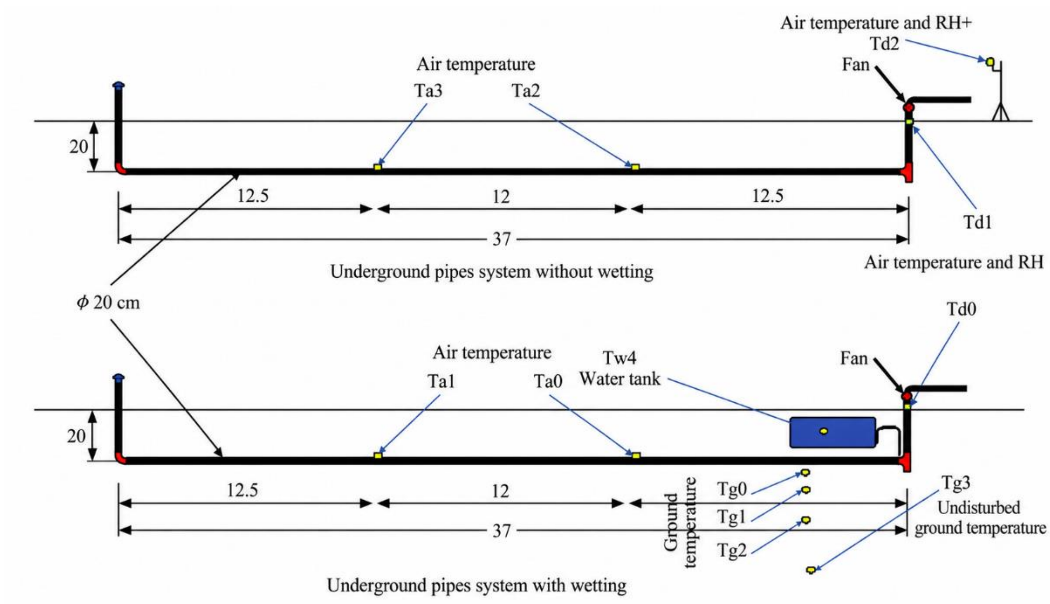


Fig II.8 Schematic of the EAHE: DE (above) and WE (below)[91]

Hasan and Muter [92] studied the influence of design parameters, including pipe length, diameter, and various design configurations, on the performance of an Earth-to-Air Heat Exchanger (EAHE) system used in poultry houses. Their findings revealed that increasing pipe length enhances cooling capacity but decreases overall system efficiency. Conversely, larger-diameter pipes showed improved thermal performance. Additionally, the study concluded that grid-shaped designs deliver optimal performance compared to coiled or spiral configurations [93]. In a separate study, they examined the impact of airflow rate on EAHE system performance. They observed that higher airflow rates lead to an increased cooling load requirement.

Harrouz et al. [94] conducted a comparison between a hybrid cooling system, which integrates a direct evaporative cooler (DEC) and an earth-to-air heat exchanger (EAHE), and a conventional DEC system, as illustrated in Fig II.9. To support this analysis, mathematical models developed to calculate the size of each system based on the house's area and thermal requirements. The findings revealed that the hybrid system offers a greater cooling capacity and performs more effectively in satisfying cooling demands throughout its operational cycle compared to the traditional DEC system. Furthermore, the hybrid setup achieved a 40% reduction in both water and air consumption rates during the summer months in contrast to the conventional DEC system.

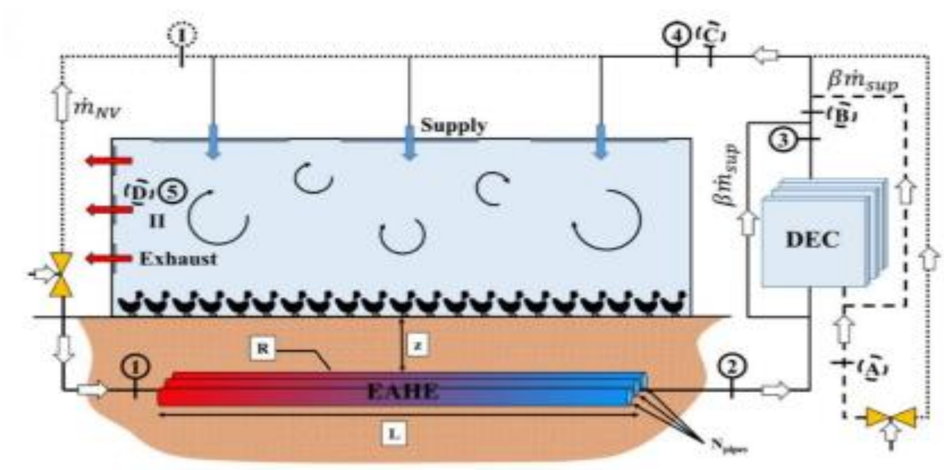


Fig II.9 Schematic of a hybrid cooling system combining DEC and EAHE[94]

II.6.4.2. Heating Systems

A study conducted by Choi et al. [95] assessed the performance of a geothermal heat pump (GHP) heating system in enhancing indoor air quality and productivity within broiler houses. The research focused on comparing gas concentration levels, energy usage, heating expenses, and overall productivity in poultry houses utilizing the GHP system versus traditional diesel-based heating systems. The findings revealed that the GHP system maintained better air quality than the conventional system, despite an observed increase in ammonia and CO2 levels indoors. While fuel consumption dropped with the GHP system, there was a rise in electricity usage. Nevertheless, total heating costs were significantly lower compared to the traditional system. Moreover, from a productivity standpoint, the GHP system showed benefits by promoting higher bird weights and reducing mortality rates relative to the conventional setup.

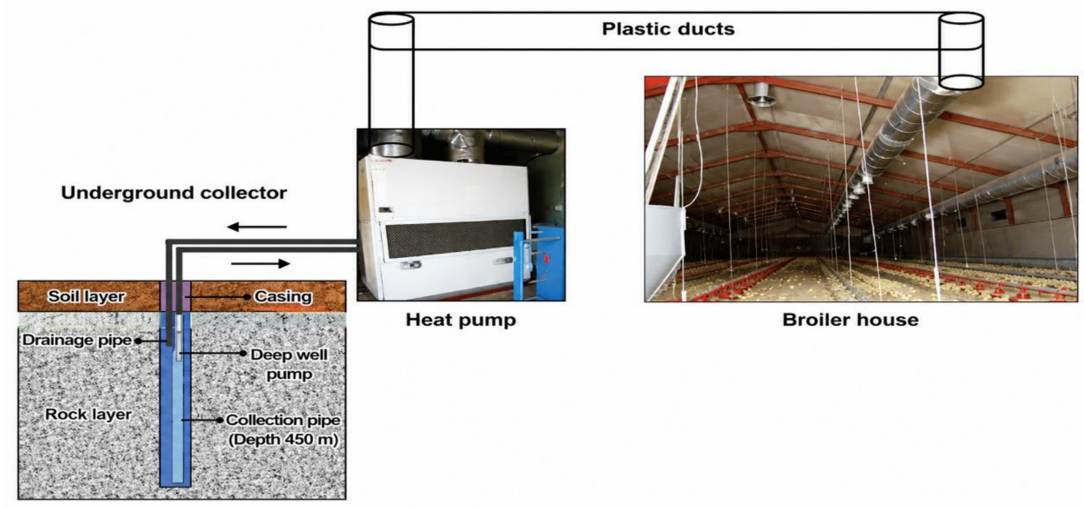


Fig II.10 Schematic diagram of the geothermal heat pump (GHP) system for the broiler house[95]

Zhou et al. [96] investigated the impact of trench spacing, ranging from 1.2 to 3.5 meters, and various configurations including dense slinky loop, horizontal straight, and standard slinky loop on ground source heat pumps designed for heating poultry houses. Their findings revealed that narrower trench spacing led to a modest 0.5°C increase in transport fluid temperature, attributed to thermal interference between the trenches. Among the configurations, the dense slinky loop demonstrated superior performance, exhibiting a 1.5°C reduction in temperature compared to the other setups.

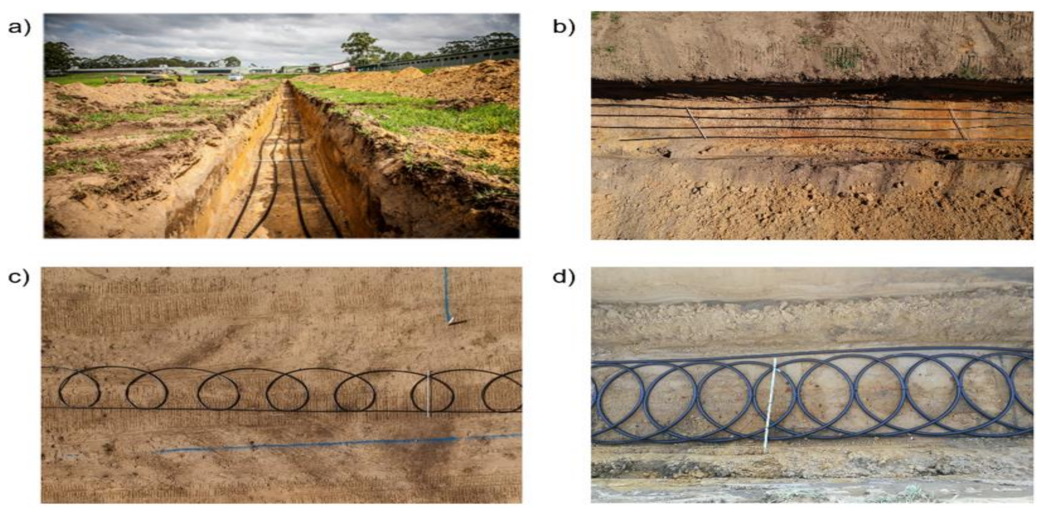


Fig II.11 Ground heat exchangers in the field: (**a**) horizontal straight loop in a trench; (**b**) horizontal straight loop; (**c**) slinky loop; (**d**) dense slinky loop [96]

Sleem et al. [97] conducted a comparative study to analyse the performance of a green poultry farm, utilizing a locally designed heating system powered by solar energy and photovoltaic panels, against a conventional poultry farm reliant on traditional electricity. The study assessed energy consumption, efficiency, and economic returns over two production cycles conducted during warm and cold seasons.

The findings revealed that energy inputs in the green farm amounted to 33,995.39 MJ in the warm season and 37,058.25 MJ in the cold season. In contrast, the traditional farm consumed higher energy levels of 40,656.97 MJ and 45,770.05 MJ, respectively. Regarding energy efficiency, the green farm proved more efficient, achieving averages of 0.58 during the warm season and 0.46 in the cold season. In comparison, the conventional farm displayed lower efficiencies of 0.50 and 0.41, respectively.

From an economic standpoint, both systems yielded negative net returns. However, a life cycle cost (LCC) analysis indicated that the conventional system was 18.89% more profitable over a 20-year period. The study concluded that small-scale poultry farming under these specific conditions is generally unprofitable. As a result, renewable energy systems might be better suited for larger farms where they could potentially contribute to significant reductions in production costs.

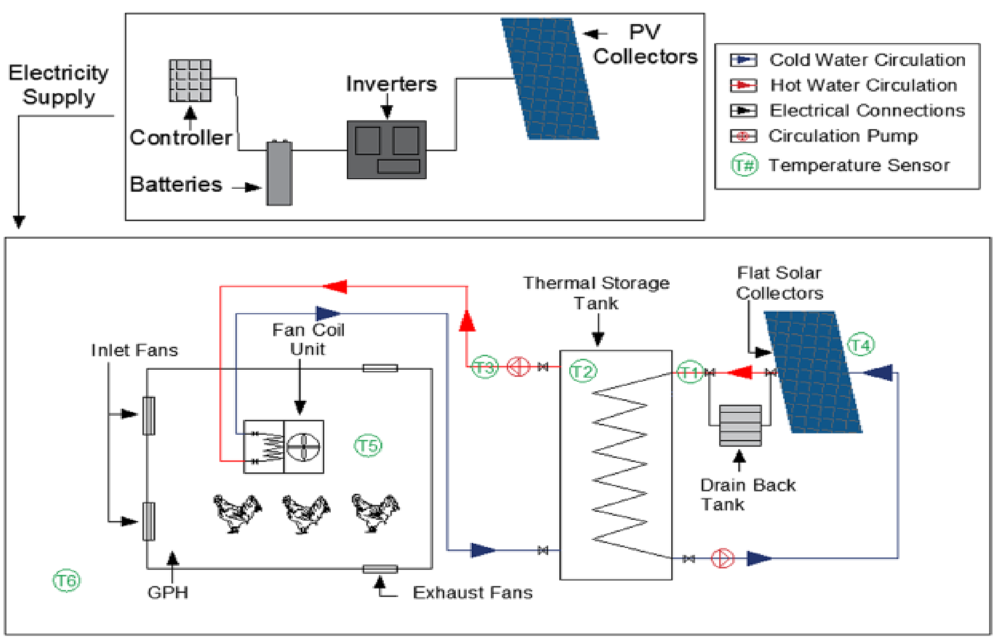


Fig II.12 Solar-assisted heating system, photovoltaic system, and system controller in the green poultry house[97]

Gurler et al. [98] conducted a study on a novel hybrid heating system designed for poultry houses. This system combines photovoltaic/thermal (PVT) panels with a polyethylene heat exchanger (PHE), which is connected to a geothermal heat pump system (FigII.13). Experimental results revealed that the heat pump generated 15.02 MWh of thermal energy per year. The solar panels not only fulfilled the annual electrical requirements of the heat pump but also produced surplus electricity that was fed back into the grid. Furthermore, the system demonstrated an annual coefficient of performance of 3.73.

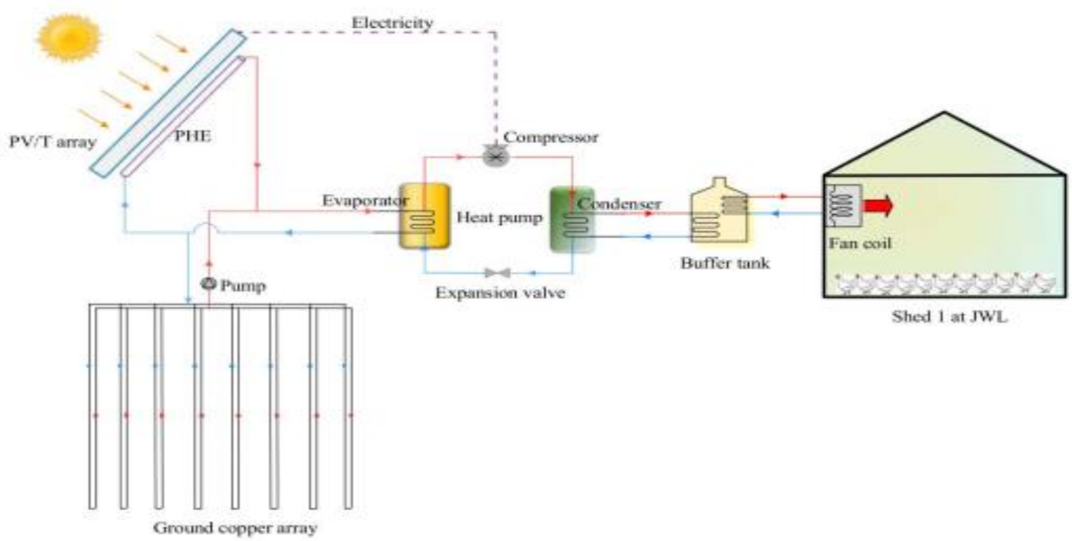


Fig II.13 Schematic diagram of the hybrid heating system.[98]

II.6.4.3. Cooling and Heating Systems

Laknizi et al. [99] conducted a study on the development and evaluation of an Earth-to-Air Heat Exchanger (EAHE) system for heating and cooling poultry houses. Their research included a parametric analysis to investigate the influence of dynamic, physical, and geometrical factors on the thermal performance of the system. The environmental impact of the EAHE was also assessed. The optimal configuration identified consisted of a polyethylene tube measuring 30 meters in length and 0.1 meters in diameter, with air circulating at a speed of 2 m/s. Under the climatic conditions of Marrakech, the energy performance of the system indicated that the heating mode could deliver 146.38 MWh annually, while the cooling mode could provide 104.3 MWh per year. Additionally, this setup was estimated to reduce greenhouse gas emissions by saving approximately 32.2 tons of CO_2 annually.

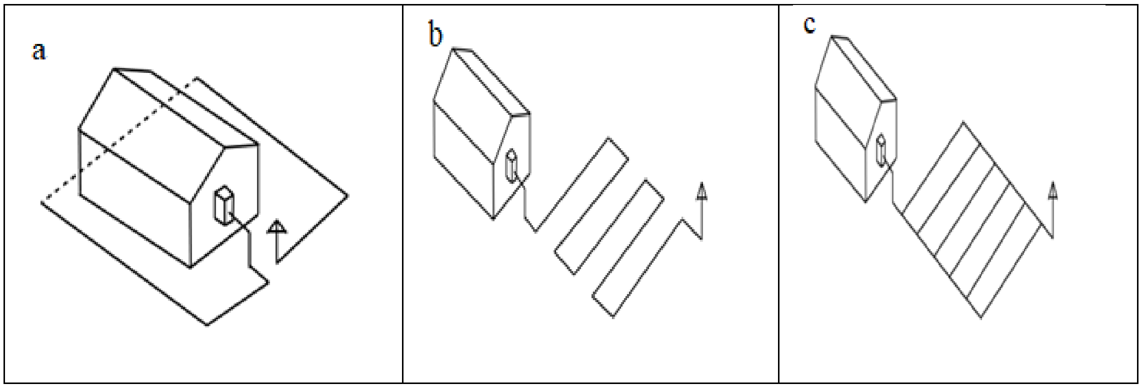


Fig II.14 The most widely used tubes' layouts: a) circular, b) meander, c) Tichelmann[99]

In a subsequent paper, Laknizi et al. [100] proposed an improved air-ground heat exchanger system that incorporated a mixing box and an air-to-air heat recovery unit, aiming to achieve more effective temperature regulation within the poultry house. The findings revealed that this integrated approach could decrease energy consumption by 34.7% in heating mode and by as much as 96% in cooling mode.

Elmer et al. [101] advanced the innovative heating system initially proposed by Gurler et al.[98] by incorporating an evaporative cooling component. The improved system demonstrated notable energy efficiency, achieving a peak thermal efficiency of 28.3% and a maximum electrical efficiency of 16% during summer conditions, while producing an annual energy output of 11,967 kWh. Moreover, it effectively maintained an indoor temperature of 24°C, even under external conditions of up to 35°C with 55% relative humidity.

II.7. Conclusion

This chapter emphasizes the significance of maintaining ideal climatic conditions in poultry houses, focusing on their influence on birds' thermal behaviour and direct effects on energy and food consumption. It also examines strategies for managing the internal environment using HVAC systems, while addressing the potential constraints associated with these technologies. As a result, there has been growing interest among researchers in exploring more energy-efficient solutions, particularly within the framework of nearly zero-energy buildings (NZEB)

While substantial progress has been achieved in this field, notable research gaps persist, especially in determining the most effective solutions for poultry houses that account for evolving environmental and production factors. These factors include bird density, ventilation needs, and humidity levels, all of which fluctuate depending on the poultry's growth stage. Although findings suggest that various renewable energy technologies (RETs) can play a pivotal role in lowering energy consumption, the majority of studies have focused on conventional or standard poultry houses. They largely overlook modern industrial poultry farms, which incorporate sophisticated designs and advanced HVAC systems to enhance energy efficiency.

Chapter III: Experimental study

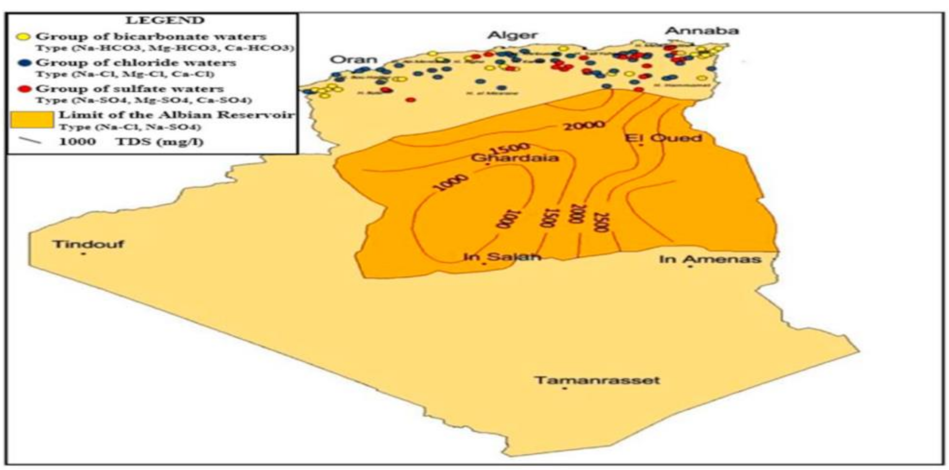
III.1 Introduction

Numerous RETs, including solar, geothermal, wind, and bioenergy, can be used in poultry house, according to earlier literature review (chapter II). However, these systems' suitability for our region features, local consumption requirements, cost-effectiveness, and sustainability are all intimately related to their effectiveness. Thus, it is crucial to choose the best renewable energy sources for the area. Our current work proposes one of geothermal systems, Earth Air Heat Exchanger (EAHE). The simplicity, high cooling and preheating potential, low operating, installation and maintenance costs, and reduction of fossil fuels and associated emissions are the primary benefits of the EAHE system. In order to investigate GAHE's efficiency for heating and cooling a typical poultry house in El Oued region, we kept watching air quality and contrast it with traditional poultry house systems. The impact of the surrounding air on the GAHE's input and output parameters, including temperature, relative humidity, carbon concentrations, and thermal efficiency.

III.2 Case of study

III.2.1 Description of the Climatic Zone

In south-eastern Algeria, known for its importance as an agricultural centre, lies the region of El Oued region. The geographical coordinates of the city of El-Oued located at 33.3676◦ N latitude and 6.8516◦ E longitude. The map of Algeria, including El Oued, is shown in Fig III.1



FigIII.1 Map of Algeria including El Oued region.

The town's climate is categorized as hot-dry, with high and variable air temperatures throughout the day and at night as well as between summer and winter. Fig III.2 shows temperature and relative humidity in El Oued from January 1, 2025, to November 3, 2025. The project is executed in collaboration with AOUIMER FILAHA Company, a private enterprise specializing in artificial egg incubation and industrial poultry fattening, managing a network of over fifty poultry houses. Their role is to provide us with a semi-modern breeding facility, fully equipped to support the rearing of broilers, enabling us to implement and assess the proposed GAHE system.[102]

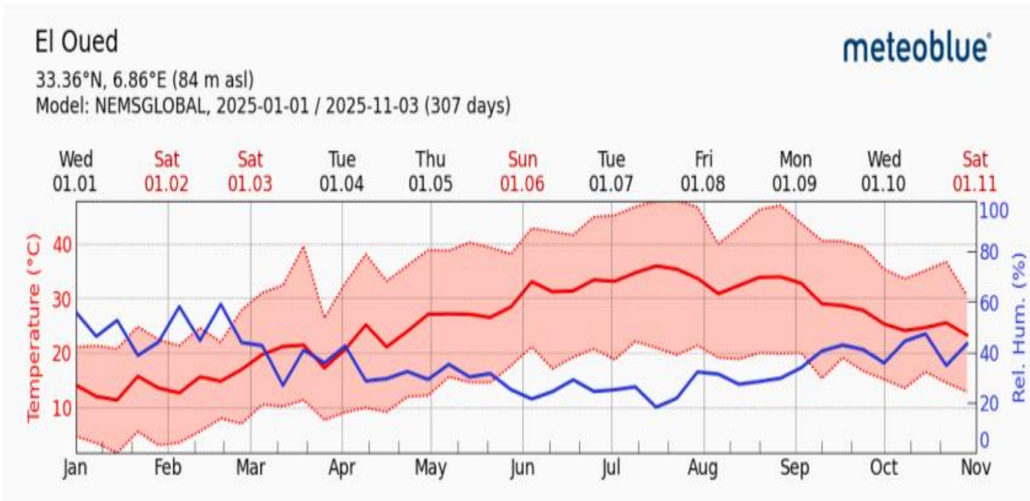


Fig III.2 Temperature and relative humidity in El Oued (2025)

III.3 Experimental setup

The geometry of GAHE system is presented in Fig III.3. A U-shaped ground-to-air heat exchanger integrated into the building. The model under study consists of a 15 vertical pipes with a diameter of 110 mm has a depth of 4.5 m. Meanwhile, a horizontal pipe features a diameter of 200 mm and a length of 48 m. additionally; a fan with a diameter of 315 mm and a power rating of 210 W is utilized in the system.

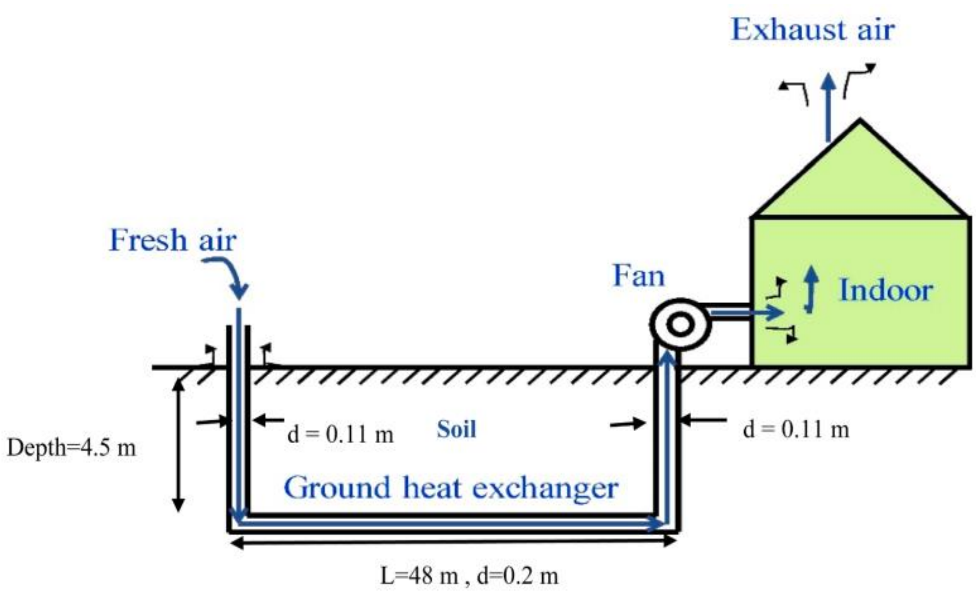


Fig III.3 A shaped ground-to-air heat exchanger

In a poultry farm, we dug nine trenches measuring 48 m x 1 m x 4.5 m. Inside, we installed fifteen underground heat exchangers, spaced approximately three meters apart. After measuring the depth of the trenches, the installation procedure for the underground heat exchanger systems took place, in the following order:

The first two trenches each contained an underground heat exchanger connected to a fan located inside the chicken coop. The same process was repeated in pairs in the subsequent trenches. The last trench contained three heat exchangers, connected to a fan. The heat exchangers were buried after the underground heating system was installed. All the trenches were made of the same type of soil: sand. The setup and implementation on site are illustrated in Fig III.4.

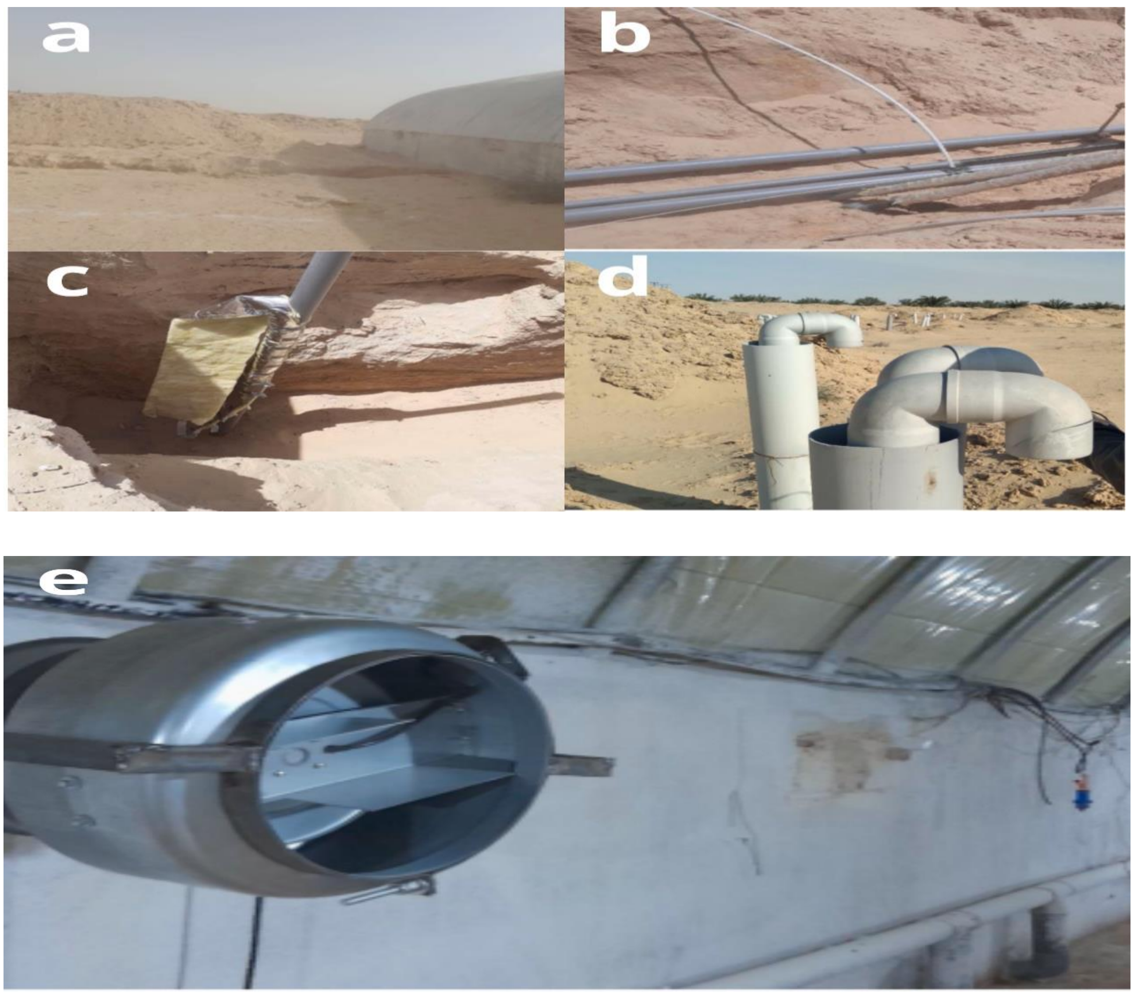


Fig III.4 (a-e) The setup and implementation on site

The parameters monitored in this study are highly dependent on local climate changes, which are themselves influenced by several other independent variables that were not controlled for in this study. Examining the benefits of fluid dynamics and heat transfer is not the primary objective of this study, this objective is to develop more relevant recommendations regarding ground air heat exchangers (GAHE) to improve indoor air thermal conditions. It is important to highlight that the variables observed in the research are greatly influenced by local climate variations, which are affected by several other independent factors not controlled in the study. It is essential to acknowledge that each measurement system, no matter how precise, has built-in flaws and uncertainties in its readings. Consequently, acquiring the precise amount is unfeasible. Uncertainty indicates mistakes of this nature. Table III.1 displays the instrumentation data employed in this research and uncertainty values. The breeding phase and experiments commenced from the chicks' initial age. Fig III.5 The experimental instruments employed in the study

Table III.1 Instrumentation data employed in measurement.

Instrument	**Type**	**Range**	**Accuracy**	**Manufacturer**	**Error**
CO and CO2 meter AQ-9901SD	CO	0 to 1000 ppm	1 x ppm	Taiwan	±(5%+2 ppm) of the reading
	CO_2	0 to 4000 ppm	1 x ppm		±40 ppm (for <1000 ppm) ±5% of reading (for 1,000 to 3,000 ppm) ±250 ppm (for >3000 ppm)
	RH	10 to 95 %	/		±3% of reading (for ≥70% RH) ±(3% reading+1% RH) (for <70% RH)
	T	0 to 50 °C	/		±0.8∘C

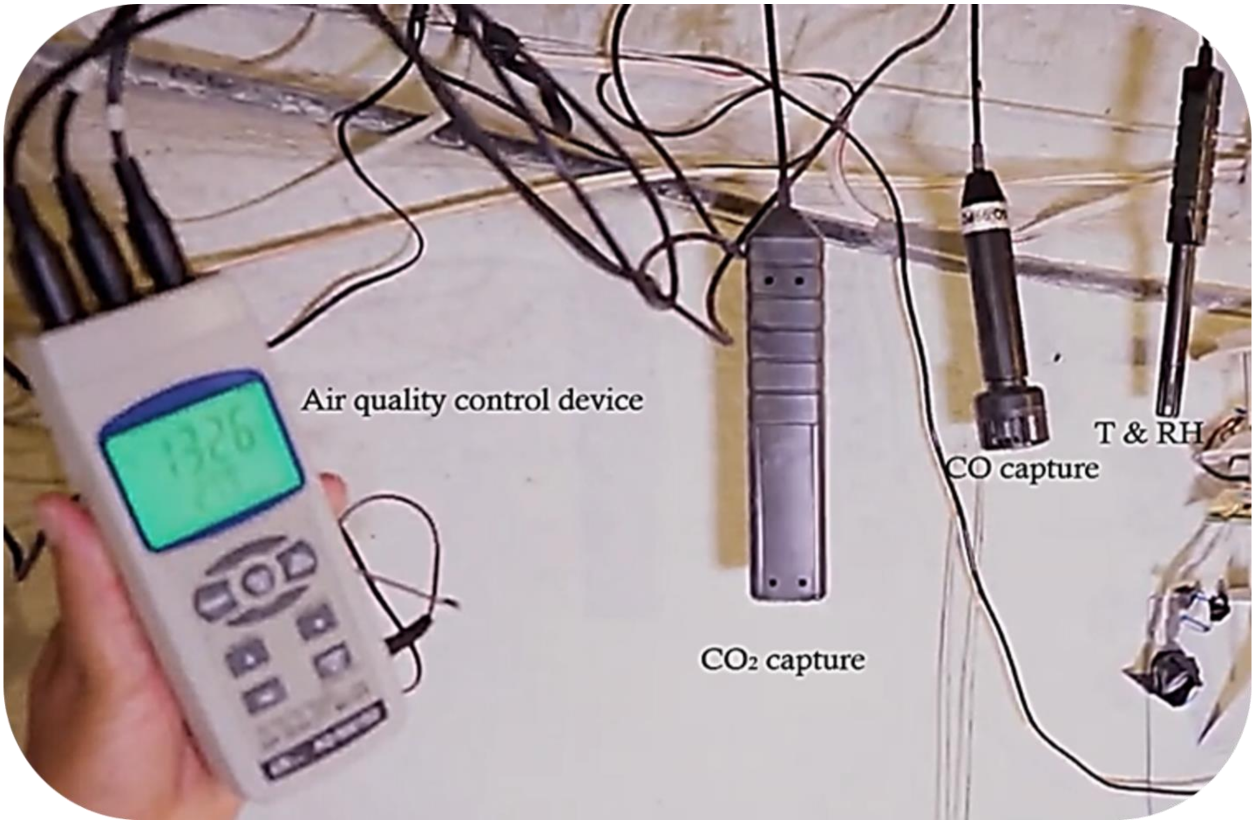


Fig III.5 The experimental instruments employed in the study

III.4 Results and discussion

Fig III.6 presents the values of air temperatures between hybrid poultry house (HPH) relies less on fuel and a geothermal system combined and traditional poultry house (TPH) depends entirely on fuel. The Temperatures was recorded during 2000min in February and March.

The curve shows that temperatures ranged between 21 and 29°C, depending on external climatic conditions and time of day. An average temperature of approximately 25°C is indicated. Comparative analysis of the internal temperature profiles reveals that the hybrid poultry house (HPH), combined with a ground air heat exchanger (GAHE), maintains a more consistently stable thermal environment compared to the traditional poultry house (TPH).

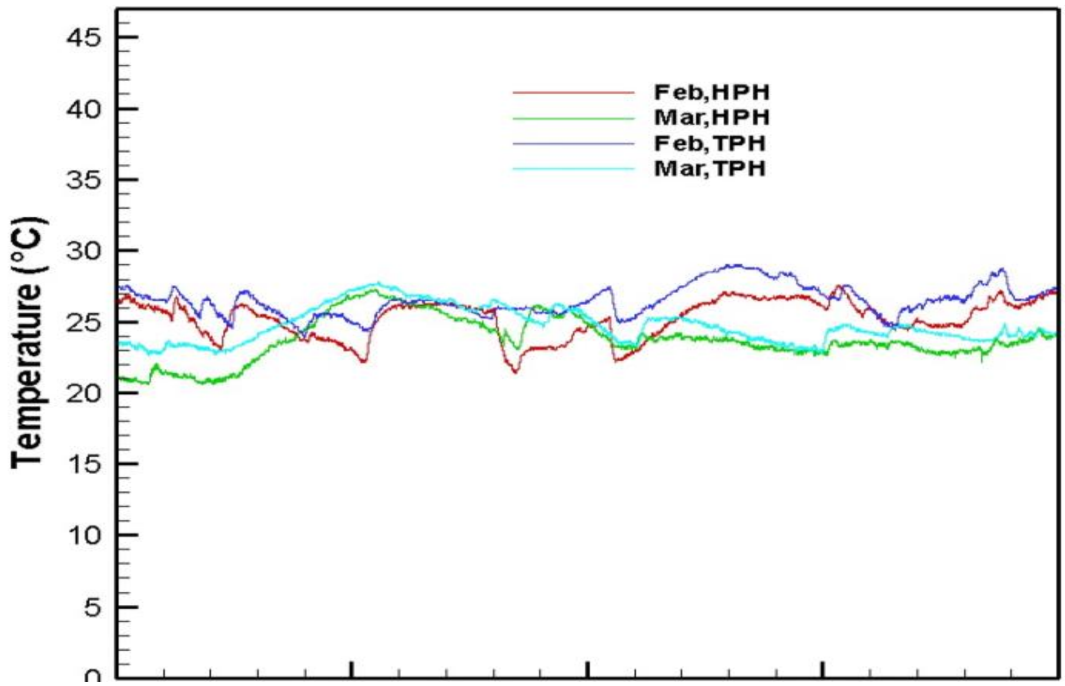


Fig III.6 The values of air temperatures between hybrid poultry house HPH and traditional poultry house TPH

In February, the traditional poultry house consistently recorded slightly higher temperatures than the hybrid poultry house for most of the monitoring period, suggesting that the TPH was more prone to heat accumulation. In contrast, the HPH maintained lower and more moderate internal temperatures, demonstrating the effectiveness of the GAHE system, which conditions the air before it enters the building.

In March, although the temperature differences between the two systems decreased slightly due to seasonal climatic variations, the hybrid poultry house maintained better thermal regulation and less fluctuation than the conventional poultry house. The significant temperature similarity between the two buildings demonstrates the potential of geothermal energy as an environmentally friendly alternative to powering the poultry house's air conditioning system.

The stable and consistent temperature inside the hybrid building (HPH) demonstrates the GAHE system's ability to use as an HVAC system, mitigating sudden temperature variations and maintaining a more balanced indoor environment. This thermal stability is extremely beneficial for poultry production, given the sensitivity of poultry to heat stress and sudden temperature fluctuations.

Fig III.7 shows the relative humidity (RH) data for a hybrid poultry house and a conventional poultry house during February and March. The monitoring data reveals a clear variation in humidity measurement performance, influenced by both seasonal variations and the house design.

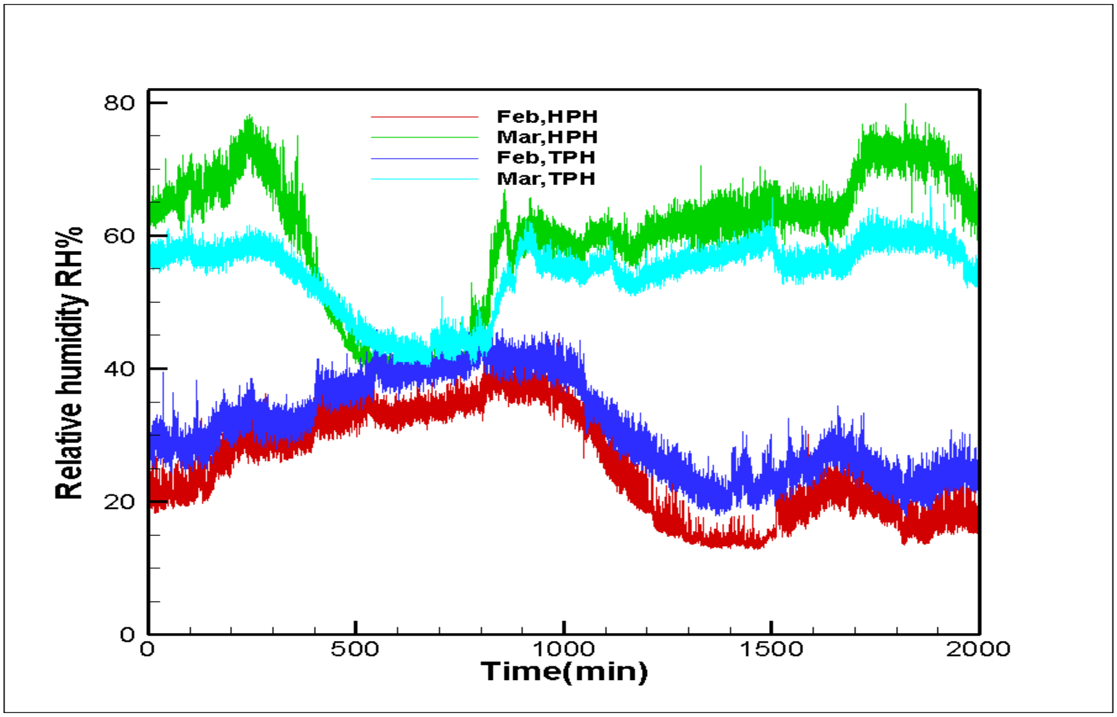


Fig III.7 Comparison of change relative humidity between HPH and TPH

In March, both systems recorded significantly higher humidity levels compared to February. The hybrid poultry house consistently maintained a higher relative humidity (between 40% and 80%) compared to the traditional poultry house (between 40% and 65%). In contrast, February data shows a drier environment, with humidity levels ranging from 15% to 45% for both buildings.

The analysis indicates an inverse relationship between the temperature curves recorded in the data and humidity levels. The hybrid poultry house, characterized by lower and more stable temperatures, by means of the GAHE, maintained higher humidity levels, as evidenced by the March data, where the average relative humidity was approximately 60%. These relative humidity values were within the range considered comfortable for broiler chickens.

Fig III.8 illustrates the carbon dioxide (CO_2) concentrations observed in the air of broiler chickens raised in hybrid and conventional rearing systems during the study. In conventional poultry houses, liquefied petroleum gas is used as the primary heating fuel. In contrast, hybrid systems utilize geothermal energy stored in the ground to heat the poultry. The data reveal a significant difference in CO_2 concentrations recorded between the two systems during the experimental period.

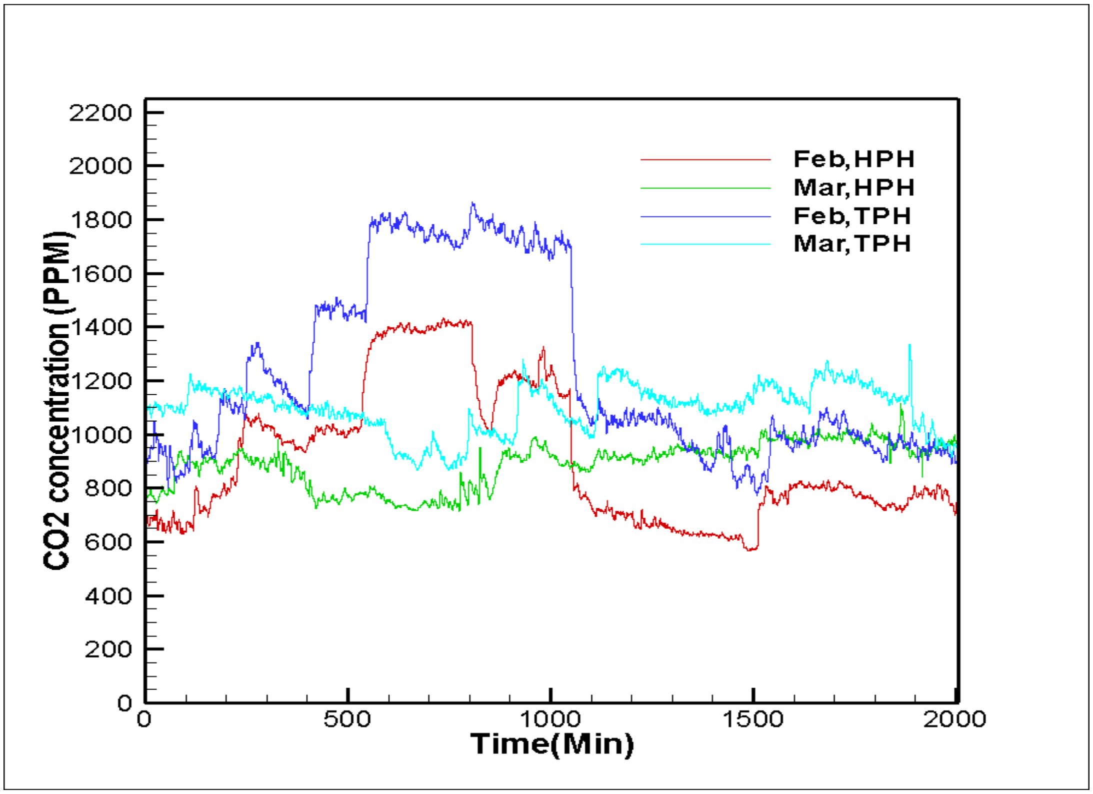


Fig III.8 Carbon dioxide CO_2 concentration in air.

Mean daily CO_2 concentrations peaked at various intervals during the study. Carbon dioxide levels fluctuated before stabilizing at approximately 1,400 ppm in the hybrid poultry house (HPH) and 1800 ppm in the traditional poultry house. The results clearly demonstrate that poultry houses powered by geothermal energy emit less carbon dioxide than conventional poultry houses. An important factor is that the geothermal system required only six gas cylinders throughout the study, compared to nine for the conventional system. This difference in consumption highlights how effectively the hybrid system reduced carbon dioxide emissions during the monitoring period.

The graph shown in Fig III.9 depicts the temperature trends of a Ground Heat Exchanger (GHE) measured over a 2000-minute interval during February, March, and May. Here, "GHEi" refers to the inlet temperature, while "GHEo" indicates the outlet temperature of the system.

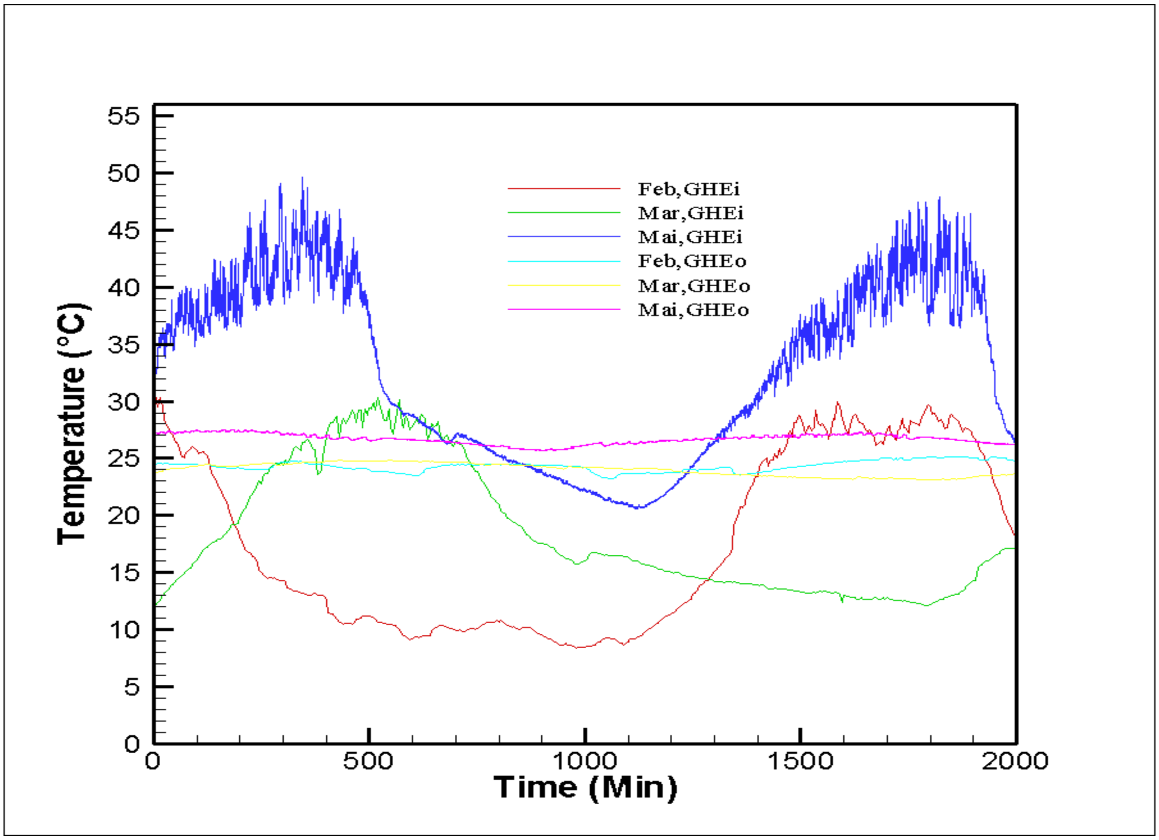


Fig III.9 The temperature across the inlet and outlet of the (GHE).

The inlet temperature exhibits marked variability and distinct seasonal variations. Observations for May (May, GHEi) reveal the strongest fluctuations, with temperatures ranging from approximately 20°C to 50°C. In comparison, the temperature profiles for March (Mar, GHEi) and February (Feb, GHEi) indicate considerably lower values. February records the coldest conditions at the inlet, with temperatures falling below 10°C and gradually rising over the observation period.

The outlet temperatures across all three months exhibit considerably greater stability compared to their corresponding inlet temperatures. In May (Mai, GHEo), the outlet temperature stays consistently around 26 to 27°C, while in March (Mar, GHEo) and February (Feb, GHEo), the outlet temperatures remain steady within the range of 23 to 25°C.

The data indicates that the ground heat exchanger functions as an effective thermal insulator, significantly mitigating the substantial temperature variations observed at the inlet. Despite the marked fluctuations at the inlet, especially noticeable in May, the system ensures a more consistent and moderate temperature at the outlet. This underscores the essential role of the soil, serving either as a heat source during colder periods or as a heat sink during warmer conditions, thereby stabilizing the air temperature before it exits the exchanger.

Fig III.10 illustrates the variation over 2000 min in relative humidity at both the inlet and outlet of the GAHE during the months of February, March, and May.

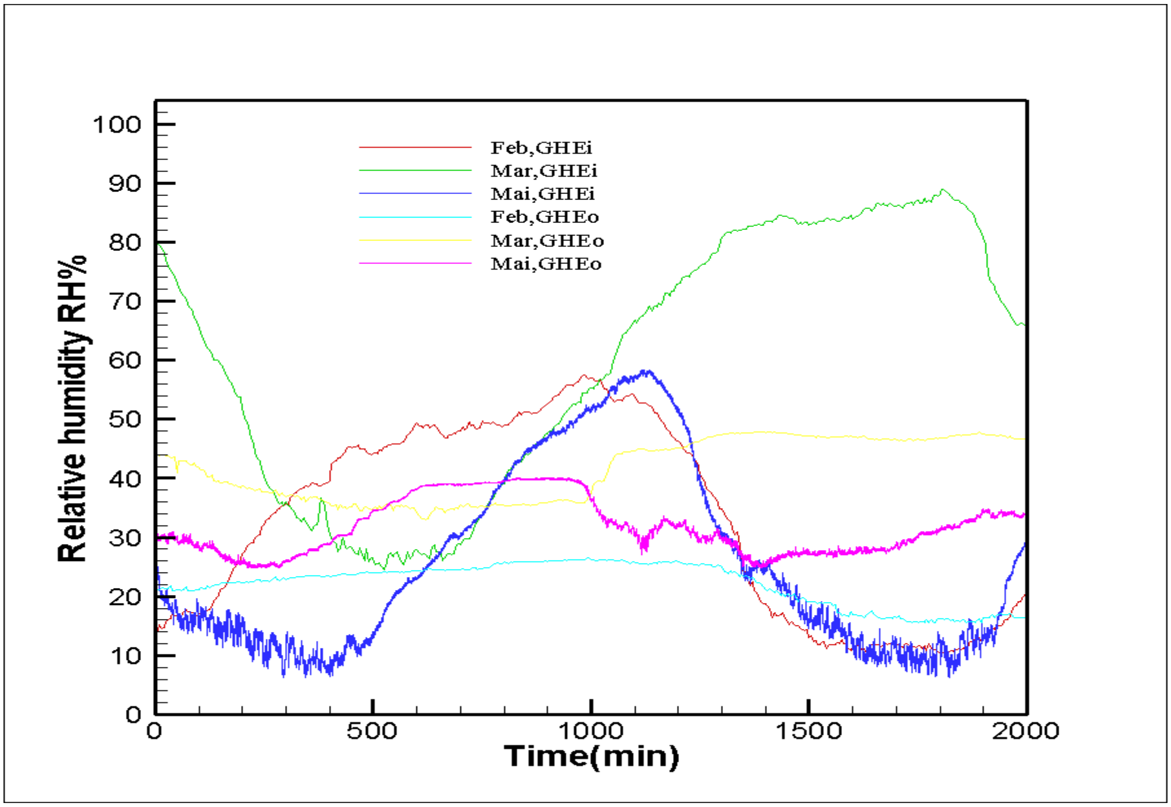


Fig III.10 The variation in relative humidity at both the inlet and outlet of the GAHE

Notable differences are observed between the conditions at the inlet (GHEi) and the outlet (GHEo). Relative humidity at the inlet exhibits significant fluctuations, predominantly influenced by the climatic conditions of the surrounding region, with values ranging broadly from 10% to 90%, depending on the specific month and time of day. In contrast, relative humidity at the outlet remains more consistent, fluctuating within a narrower range of approximately 25% to 50%. This stability is a result of the fan installed in the system, which aids in air circulation and renewal, thereby reducing excessive moisture levels within the buried pipe.

The observed pattern underscores the geothermal system's strong damping effect, effectively mitigating external humidity variations through heat and mass exchange with the surrounding soil.

During February and May, substantial shifts in inlet humidity are successfully moderated at the outlet. Similarly, in March, despite pronounced fluctuations at the inlet, outlet humidity remains relatively stable. This consistency is attributed to the thermal inertia of the soil and the interplay between temperature and humidity, which may involve processes such as condensation or evaporation occurring within the heat exchanger.

Overall, it can be stated that the air quality characteristics of the heat exchanger examined are acceptable, as poultry require average temperatures ranging from 26 to 35 ◦C and relative humidity levels ranging from 60 to 75 %

The graph provided in Fig III.11 highlights the humidity regulation and dehumidification performance of a Ground-to-Air Heat Exchanger (GAHE) by analysing the dew point temperatures of air at its inlet (GHEi) and outlet (GHEo) over a 3,000-minute operational period. The dew point temperature, being directly tied to the air's absolute moisture content (humidity ratio), allows for an insightful comparison between the two curves, showcasing how the system handles moisture fluctuations within the subsurface environment.

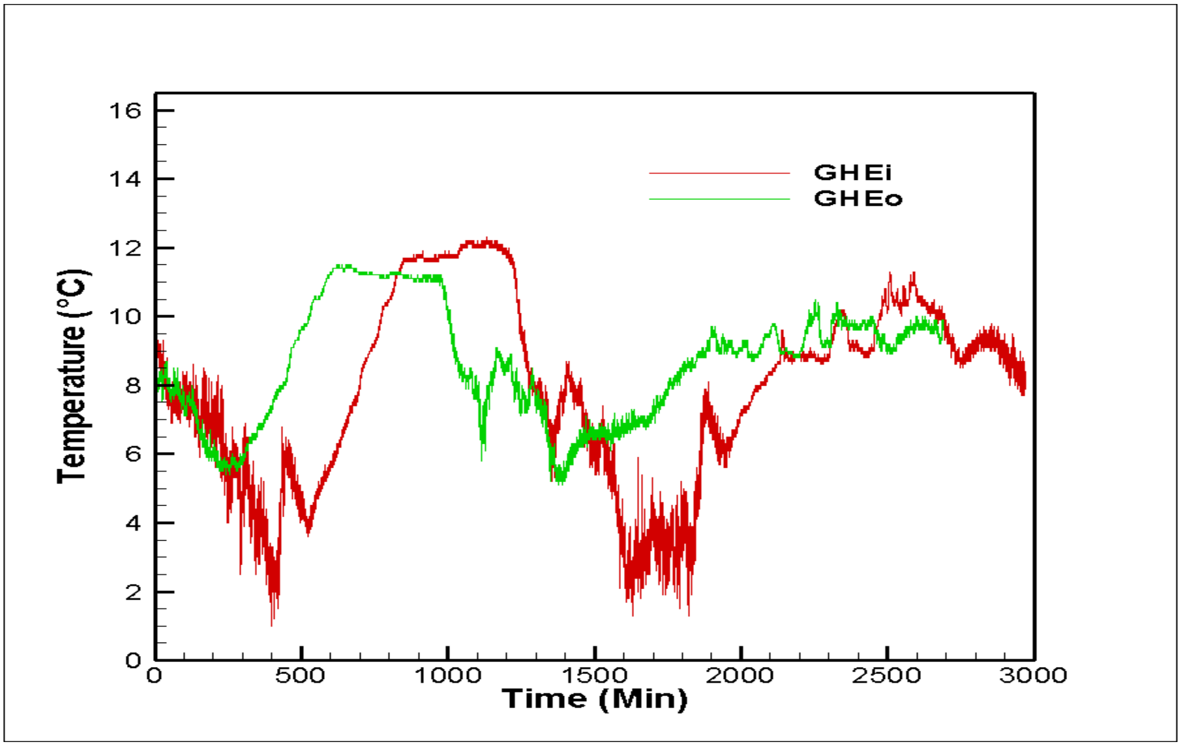


Fig III.11 Dew point temperature values on GHEi and GHEo over 3000 min.

The inlet dew point temperature, represented by the red line, shows significant variability, oscillating between 2°C and 12°C. These fluctuations indicate a highly dynamic latent load in the incoming ambient air, with peaks (e.g., around 1100 minutes) corresponding to high humidity levels and sharp reductions (e.g., at 400 and 1700 minutes) reflecting extremely dry air conditions.

When the inlet dew point notably exceeds the outlet dew point particularly between 800 and 1200 minutes the system performs active dehumidification. As the warm, humid inlet air flows through the underground pipes, it cools below its dew point temperature. This cooling causes condensation of water vapor onto the colder pipe surfaces, effectively reducing the moisture content in the air. The resulting drier air is discharged at the outlet (GHEo).

Conversely, during intervals when the inlet dew point falls significantly below the outlet dew point observed at approximately 400 and 1700 minutes the outlet air emerges with increased moisture relative to the inlet. This reflects a moisture buffering mechanism. As the dry inlet air passes through the GAHE pipes, it absorbs residual condensation from previous cycles on the pipe walls, adding moisture to the outgoing stream.

This dew point analysis underscores that the GAHE functions not only as a sensible heat exchanger but also as an efficient passive regulator of latent heat (humidity). By mitigating extreme variations in humidity and narrowing the outlet dew point range to a consistent band of 8°C to 10°C toward the latter part of the cycle, the system demonstrates its ability to sustain stable indoor humidity levels. This feature significantly reduces latent cooling demands on downstream HVAC systems while contributing to a more comfortable indoor environment.

Fig III.12 highlights the transient efficiency patterns of the heat exchanger over the monitoring period. The findings indicate exceptional efficiency, particularly during the month of March. Nonetheless, the system's performance shows some variability in efficiency, influenced by hourly and daily fluctuations. Notably, temperature changes during the experiment impact the shape of the efficiency curve. As a result, anomalies were observed in February due to uncontrolled conditions affecting the system. The thermal efficiency of the GHE defines as the ratio of the air temperature drop between the outlet and the inlet of the GHE and the difference between soil and inlet air temperatures:

$$\eta = \frac{T_i - T_o}{T_i - T_{soil}} \qquad \text{III.1}$$

Overall, the average thermal efficiency of the heat exchanger design is estimated at η = 91.13%-92.56%, which is considered a strong performance, especially given its manual design and the use of locally manufactured materials for this experimental study. For further context, a comparative analysis with other systems under investigation was performed to highlight the designed GAHE system's efficiency, with the corresponding results. It proposes comparing the experimental findings with those of previous research investigations.

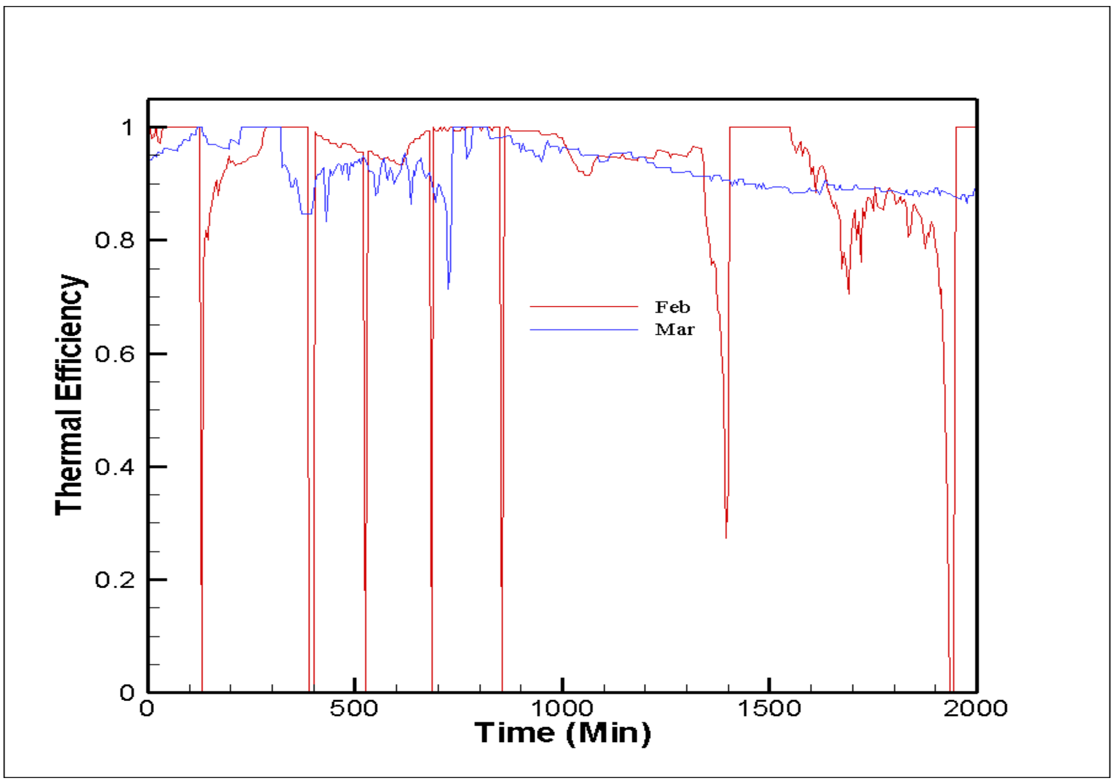


Fig III.12 Thermal efficiency patterns of the heat exchanger over the monitoring period (February) and (March)

Misra et al. [103]Evaluated the thermal efficiency of dry and wet soil in the Jaipur area of India utilizing an EAHE system with a pipe length of L = 60 m. The findings indicate that η=78% and that the pipe length may be minimized using the wet EAHE.

In the Adrar region of Algeria, Belatrache et al. [104](2017) conducted a simulation of a ground air heat exchanger (GAHE) with a length of 23.42 m for building air conditioning under the mild climatic conditions prevalent in southern Algeria. Their simulation revealed a temperature differential of 17°C between the intake and exit of the GAHE. Based on these findings, they concluded that this technology is both feasible and promotes significant energy conservation.

In a parallel study conducted by Boughanmi et al. [105] (2017), a conic basket ground heat exchanger (CBGHE) was examined in Borj Cedria, Tunisia, specifically evaluating its energy performance. Similarly, Benhammou and Draoui [106](2015) undertook an analysis of a GAHE configuration with a 50 m pipe length, reporting an estimated efficiency of 75%. However, their experimental setup achieved a slightly reduced efficiency of 62%.

In a more recent investigation, Hadjadj et al. [107](2025) conducted an experimental assessment of heat performance in a GAHE using water as the heat exchange medium (HWAHE). Their findings demonstrated an efficiency of 92%, which aligns closely with results obtained from their innovative design that involves wrapping a flexible pipe around a column in a spiral configuration to enhance heat exchange. Notably, the study pointed out that the relative differences in heat exchanger efficiencies across different cases were less than 64%. These variations were attributed to differing regional climatic conditions, GAHE designs, and the physical properties of the local soil and air.

Moreover, the research highlighted that relative temperature deviations between their model and those discussed in previous studies are contingent upon specific case parameters. The minimum and maximum deviations recorded in comparison to experimental data from Bansal et al.[108] (2010) and the model proposed by Hadjadj et al. [107]ranged from 3.30% to 36.77%. These findings further underscore the influence of localized environmental and design-related factors on heat exchanger performance.

III.4 Conclusion

In this study, a custom-designed underfloor heating and cooling system independently evaluated to determine its thermal efficiency and environmental impact. The air quality examined as a fundamental component to assess the overall functionality of the system.

The design parameters, including soil depth, pipe dimensions, and material selection, were carefully chosen based on an in-depth review of prior research. The region, due to its harsh desert climate, was a challenge in determining the system's efficiency, as the majority of annual operating hours fall outside the poultry's thermal comfort zone. despite that, the proposed system effectively regulated air temperature during both hot and cold seasons, maintaining a consistent range of 24°C to 27°C. On an environmental level, the system played a crucial role in reducing carbon dioxide emissions.

Finally, the efficiency of the proposed system is evident in its ability to mitigate extreme temperatures, delay sudden temperature fluctuations, and enhance general environmental conditions without relying excessively on mechanical cooling. This not only reduces energy consumption but also improves thermal stability. Moreover, the system positively affects poultry productivity by minimizing heat stress, leading to better growth rates and improved feed efficiency

Conclusion general

Poultry farms are notable for their elevated thermal demand and significant energy usage, both of which are vital to sustaining optimal indoor environmental conditions. As a result, they are substantial contributors to energy consumption and environmental emissions. To address these challenges, the present study explored the adoption of renewable energy technologies, emphasizing underfloor heating and cooling systems as a sustainable solution for meeting, a portion of these thermal needs. The research provides a thorough analysis, encompassing an in-depth understanding of indoor environmental requirements, identification of key obstacles, and a critical review of past studies in this domain.

The findings reveal that the proposed system achieved an impressive efficiency of approximately 91.13%-92.56%. Environmentally, the system serves as a clean and sustainable option, generating no industrial waste over its operational lifespan while significantly reducing embedded carbon emissions over time.

To improve thermal performance levels at the outlet of the ground-air heat exchanger in hybrid poultry houses, the following strategies can be considered:

- Increasing the soil moisture around the buried pipes to enhance heat transfer efficiency and to mitigate excessive air dryness.

- Incorporating a controlled humidification system at the GAHE outlet to regulate humidity more precisely.

Furthermore, the air-cooled heating and cooling system could provide valuable support in buildings with extensive interior spaces and high heat demands or serve as the primary solution in smaller constructions with low heat requirements.

Since heat needs fluctuate depending on the age and physiological stages of poultry, it is essential to carry out dynamic analyses to evaluate how effectively the system can maintain optimal indoor conditions throughout various growth phases.

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