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Abstract

This study investigates the integration of renewable energy technologies, particularly geothermal and solar energy, into poultry housing systems in arid regions, with a focus on El Oued, Algeria. The research aims to develop and assess a geothermal HVAC system tailored for broiler chicken farms, promoting energy efficiency, improved animal welfare, and economic viability. A comprehensive review of poultry housing requirements, thermal comfort, ventilation strategies, and environmental stressors—such as heat stress—was conducted. The study compares traditional and modern poultry systems, emphasizing the advantages of hybrid renewable energy systems (HRES) combining solar photovoltaic and geothermal energy. The system design includes photovoltaic sizing, geothermal heat pump implementation, and ventilation optimization. Field data from local poultry farms inform the analysis, revealing substantial performance gains, reduced mortality, and enhanced productivity in modern facilities. Results suggest that adopting HRES in poultry farming can significantly reduce reliance on fossil fuels, lower operational costs, and contribute to sustainable agriculture in desert climates.

الملخص

تتناول هذه الدراسة دمج تقنيات الطاقة المتجددة، وخصوصًا الطاقة الحرارية الجوفية والطاقة الشمسية، في أنظمة إسكان الدواجن في المناطق الجافة، مع التركيز على منطقة الوادي في الجزائر. يهدف البحث إلى تطوير وتقييم نظام تدفئة وتهوية وتكييف (HVAC) يعمل بالطاقة الجوفية ومخصص لمزارع دجاج ، وذلك لتعزيز كفاءة استخدام الطاقة، وتحسين جودة الدواجن ، وزيادة الجدوى الاقتصادية. تم إجراء مراجعة شاملة لمتطلبات إسكان الدواجن، استراتيجيات التهوية والعوامل البيئية الضاغطة مثل الإجهاد الحراري. كما تم إجراء مقارنة بين الأنظمة التقليدية والحديثة في تربية الدواجن، مع إبراز مزايا أنظمة الطاقة المتجددة الهجينة (HRES) التي تجمع بين الطاقة الشمسية الكهروضوئية والطاقة الجوفية. يشمل تصميم النظام تحديد حجم الألواح الشمسية، وتطبيق مضخة حرارية جوفية، وتحسين نظام التهوية. وقد استخدمت بيانات ميدانية من مزارع دواجن محلية في التحليل، مما أظهر تحسنًا كبيرًا في الأداء، وانخفاضًا في معدل النفوق، وزيادة في الإنتاجية في المنشآت الحديثة. وتشير النتائج إلى أن اعتماد أنظمة الطاقة المتجددة الهجينة في تربية الدواجن يمكن أن يقلل بشكل كبير من الاعتماد على الوقود الأحفوري، ويساهم في الزراعة المستدامة في المناخات الصحراوية

DEDICATION

I dedicate this modest work to my mother and father, symbols of love and affection, who sacrificed all their time for my happiness and success, and I hope that they will find here a testimony of my deep gratitude.

I also extend my love to all my family members, my uncles and aunts, my brothers and sisters, who supported me throughout my studies, and to all my friends and colleagues, and to all those I love.

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List of abbreviations

HVAC: Heating Ventilation and Air Conditioning.

IEA: International Energy Agency.

HRES: Hybrid Renewable Energy Systems.

PV/T: photovoltaic/thermal.

EAHE: Earth Air Heat Exchangers.

WTO: World Trade Organization.

General Introduction:

General Introduction:

The globe has experienced an intensification of global environmental concerns since the end of the twentieth century and the beginning of the twenty-first century, arguably the most notable of which is the phenomenon of global warming and climate change. Many publications point to the significance of traditional energy sources (fossil fuels) in these alarming statistics, which anticipate the worst if no structural changes to the energy paradigm are made, particularly in developing nations [1].

Renewable energy sources, including wind, solar, and hydrogen power, are better for the future. Among these, geothermal energy extracted from the Earth's internal heat stands out for its capacity to operate independently of weather conditions and deliver consistent, 24-hour energy. It is utilized for various applications, including heating, cooling, bathing, and medicinal purposes. With suitable infrastructure, geothermal power can compete economically with conventional energy sources such as coal and natural gas. By reducing reliance on fuel imports and enhancing national energy security, geothermal energy presents a viable alternative. Additionally, it is ecologically sustainable and globally accessible, making it a key component in the renewable energy transition [1].

Renewable energy is derived from natural sources that replenish on a human timescale; examples include sunlight, wind, rain, tides, waves, and geothermal heat [1]. In contrast to fossil fuels, which are depleted much faster than they can be replenished, most renewable sources are replenished rapidly. However, not all renewable energy sources are automatically sustainable; for example, specific biomass resources become unsustainable under current usage patterns [2][3].

Geothermal HVAC (Heating, Ventilation, and Air Conditioning) is a technology that harnesses geothermal energy for climate control. It functions by transferring the Earth's stable subsurface temperature into indoor environments, using components such as a ground-source heat pump and an underground heat exchanger (loop system). This method allows efficient heating and cooling of buildings, including homes, greenhouses, and animal shelters [4].

In this research, we address a practical application of geothermal energy: the development of a geothermal heating, ventilation, and air conditioning (HVAC) system specifically designed for poultry houses. The goal is to ensure an ideal, uniform distribution of heat, ventilation, and air

conditioning at a lower cost, particularly suited for arid regions where climate extremes challenge poultry productivity. This system promises to enhance energy efficiency, improve animal welfare, and increase economic returns for poultry farmers [4].

The objective of our work is to study the heating, ventilation, and air conditioning system powered by geothermal energy and evaluate its integration in poultry farms located in arid areas. This will be presented in four main chapters:

- Chapter One: A literature review on broiler chickens and their housing systems, including breeding regimens, operational techniques, and planned interventions.
- Chapter Two: A detailed estimation of broiler chickens' environmental needs—including temperature, ventilation, and lighting—throughout their lifecycle and across seasons.
- Chapter Three: A technical exploration of poultry house construction characteristics, such as geometry, material choices, insulation, and design features impacting thermal performance.
- Chapter Four: Analysis of the energy-consuming equipment used in poultry facilities (type, power, efficiency, and placement) along with a study of thermal and air quality demands to ensure optimal poultry house operation.

Chapter 01

Literature review on Broilers and its housing

I.1 Introduction :

According to the International Energy Agency (IEA), fossil fuels account for 81% of the world's primary energy consumption. Although these resources are depleting rapidly, their use has surged due to technological advancements, leading to serious environmental consequences such as acid rain and global warming [4]. In response, many developed and developing nations are adopting sustainable solutions to enhance energy efficiency in buildings. However, despite the global availability of renewable energy sources, the poultry industry still heavily depends on fossil fuels for heating and cooling needs [6]. The integration of Hybrid Renewable Energy Systems (HRES), particularly those combining solar and geothermal energy, presents a promising path toward reducing this dependency by leveraging complementary energy profiles for year-round efficiency.

In poultry farming, maintaining optimal moisture levels and appropriate litter conditions is essential for the health and welfare of chickens [5]. One of the most critical environmental challenges faced by poultry producers is heat stress, especially during the summer months. If a bird's body temperature exceeds its normal level of 41°C by more than 4°C, it can lead to fatalities [6] [7]. This stress significantly impacts broiler production, causing substantial energy and financial losses within the livestock sector. For instance, in the United States alone, heat stress in poultry houses is estimated to result in annual losses ranging from \$127.3 million to \$164.6 million, representing approximately 7.0% to 7.5% of total sector losses [8] [9]. The implementation of HRES could alleviate heat-related energy burdens by providing reliable, renewable heating and cooling solutions, especially in off-grid or rural farming areas.

To safeguard poultry health, breeders must adopt appropriate management strategies. The thermoneutral zone the optimal temperature range for chickens varies with age, as shown in Figure 1 [6]. While European regulations provide guidelines for bird density, they often overlook broader welfare considerations within poultry housing [8]. In colder climates, standard ventilation systems typically operate on timer-controlled minimum ventilation, with airflow speeds around 0.5 m/s [10] [11]. Coupling geothermal systems for stable subsurface temperature exchange with solar energy for peak daytime loads can ensure more consistent indoor conditions, reduce over-reliance on mechanical systems, and cut down operational costs.

Meanwhile, poultry farming in Algeria, particularly in the El-Oued region, continues to face challenges in providing adequate environmental conditions. Many breeders still depend on conventional methods such as fossil fuels and gas for heating, ventilation, air conditioning, and lighting, highlighting the need for modernized and sustainable practices. The adoption of HRES tailored to local climatic conditions such as high solar irradiance and accessible geothermal gradients can offer Algerian poultry farms a viable path to improving energy efficiency, reducing emissions, and enhancing animal welfare through more stable and environmentally friendly microclimates.

I.2 poultry houses :

The design of poultry housing plays a vital role in shaping the indoor climate, which directly affects the birds' health, growth, and productivity. Consequently, the choice of a chicken housing system for a poultry farm is largely influenced by the region's prevailing climatic conditions. In tropical regions, the open poultry house system is often preferred due to its simple construction, effective natural heat regulation, and low operational costs. In contrast, controlled poultry house systems are more commonly used in temperate climates, where maintaining consistent indoor conditions is essential [12] [13] [14].



Figure I. 1: poultry houses [12].

I.3 Poultry birds and their thermoregulatory mechanism:

Birds are feathered, oviparous animals with a high metabolic rate and typically breathe at a rate of 40 to 50 breaths per minute [15]. Their average internal body temperature ranges between 39°C and 42.2°C [16] [17] [18]. During hot weather, poultry birds regulate their body temperature and maintain thermal balance primarily through heat loss mechanisms such as conduction, convection, radiation, and evaporative cooling [5] [19] [20].

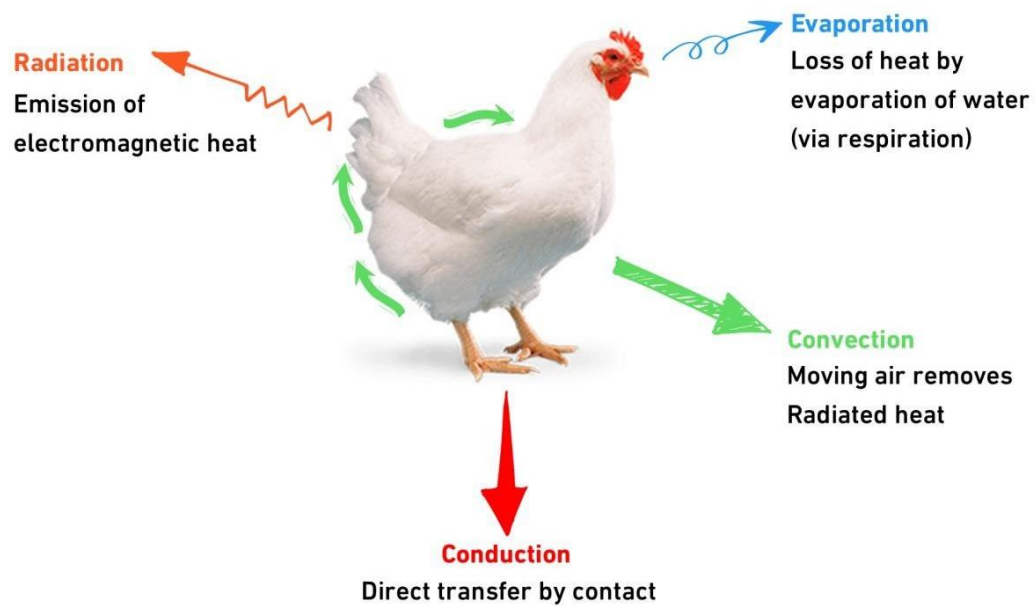


Figure I. 2: Poultry thermoregulation mechanism.

Sensible heat loss through convection, radiation, and conduction is most effective when the ambient temperature is at or below the bird's thermoneutral zone. Within this zone, approximately 60% of the heat dissipated during body temperature regulation occurs through evaporative cooling [5]. Sensible heat is primarily lost through exposed areas such as the wattles, shanks, and other featherless regions around the neck and wings [21]. This form of heat loss does not impact the bird's behavior, feed intake, or metabolism [22]. The effectiveness of sensible heat loss depends on the temperature difference between the bird's body and its surrounding environment.

When ambient temperatures exceed 24°C, evaporative cooling—or latent heat loss—becomes the main method of heat dissipation for birds of all ages [21]. At temperatures above the thermoneutral zone, birds rely on panting to lose heat through evaporation from their respiratory tract. However, this process diverts energy away from growth and development. Prolonged panting can also lead to dehydration and respiratory alkalosis, caused by a decrease in blood pH from excessive carbon dioxide loss and inadequate water intake [21]. High humidity levels can further complicate evaporative cooling, as water does not evaporate as efficiently. This poses a challenge in humid climates, where poultry producers often rely on evaporative cooling systems to manage heat during the summer months [5].

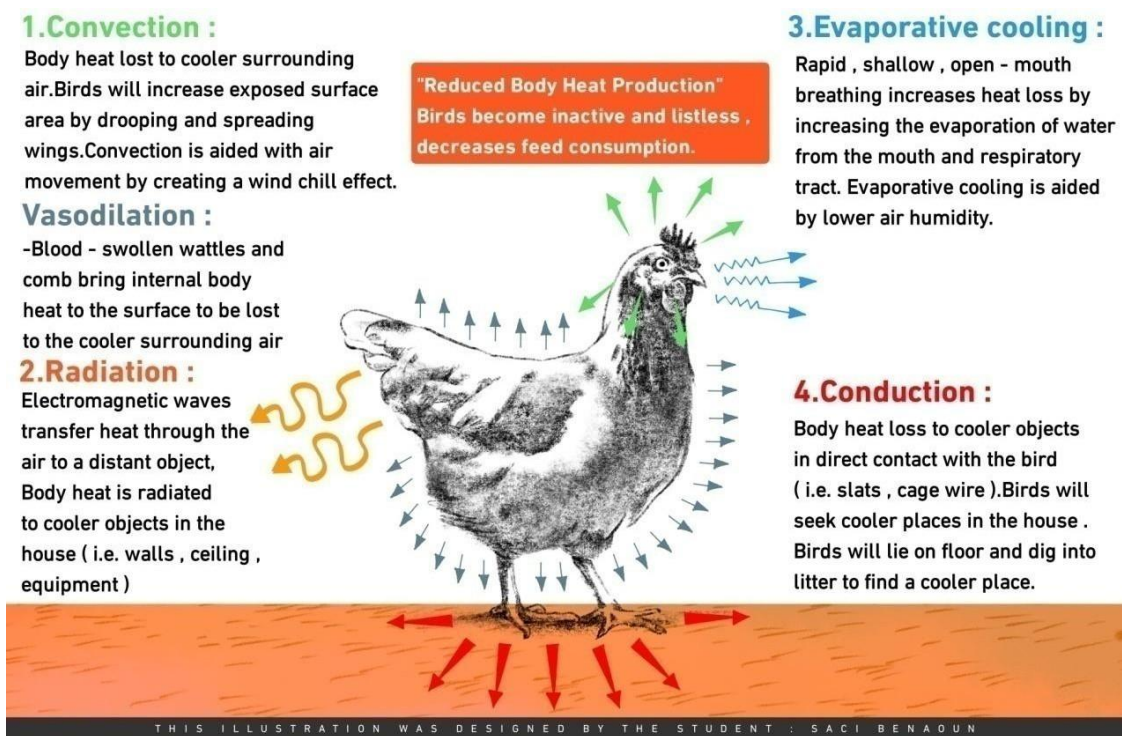


Figure I. 3: thermoregulation.

Increasing the volume and speed of airflow over birds enhances heat loss through convection, helps remove heat accumulated inside the poultry house, and reduces the negative impact of high humidity on evaporative cooling [5]. In a study by Simmons et al. [23], 3 week old male broilers were exposed to a cyclic temperature range of 25–30–25°C in a controlled environment over a four

week period, with varying wind speeds: still air (0.25 m/s), 2 m/s, and 3 m/s. The results showed that higher airspeeds positively affected the growth and development of older birds.

Water is a crucial resource in poultry production, not only for its mineral content but also for its impact on feed intake [24]. Modern poultry operations have largely replaced traditional open watering systems with nipple drinkers, which provide cleaner water, reduce spillage, and minimize the labor required for maintenance. In a study by May et al. [25], chickens raised with open water systems consumed more water than those with nipple drinkers. However, when raised under controlled conditions with air velocities of 0.25 and 2.1 m/s, birds using nipple drinkers achieved higher weight gain and better feed conversion rates compared to those using open water systems [26]. Therefore, maintaining proper ventilation in poultry houses is essential, as it enables birds to regulate their body temperature effectively through sensible heat loss.

I.4 Heat stress in chicken :

Heat stress is a widespread issue in the poultry industry, especially in meat and egg production. Chickens begin to experience heat stress when the ambient temperature reaches or exceeds 26.7°C. At this point, they start panting, which can negatively affect their optimal growth rate, hatching success, egg size, eggshell quality, and overall egg production. The situation worsens when high humidity accompanies elevated temperatures. Heat stress has been associated with reduced comfort, slower growth rates, poorer feed conversion, and lower live weight gain in broilers [21].

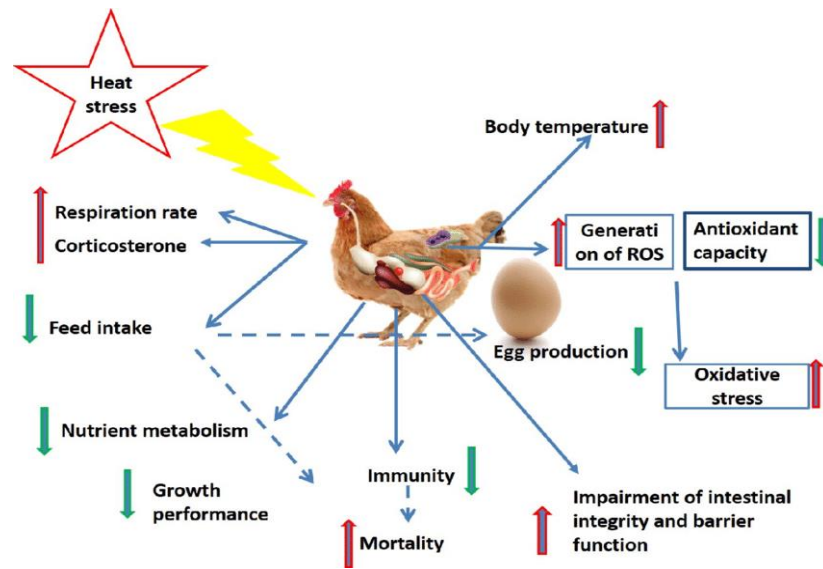


Figure I. 4: Heat stress in chicken.

Acute heat stress occurs when birds are exposed to high temperatures for a short duration, while chronic heat stress results from prolonged exposure to elevated temperatures. Birds raised in open-sided shelters commonly used in tropical regions are particularly susceptible to chronic heat stress. This prolonged exposure has been shown to adversely affect growth and production efficiency, egg and meat quality, embryonic development, reproductive performance, immune function, and the incidence of disease in broilers, laying hens, and breeders [21, 27, 28, 29, 30, 31].

I.5 Effects of internal climate conditions on chicken :

Understanding the influence of indoor climatic conditions in a poultry house on bird behavior and responses is essential, as it directly affects heat management in poultry production. This knowledge is crucial for informing the architectural design of open air poultry houses aimed at reducing heat stress and ensuring optimal productivity, particularly in arid regions. Key climatic factors to consider include temperature, relative humidity, air composition, airflow speed, and lighting conditions.

I.5.1 Temperature :

The optimal temperature range for different classes and age groups of chickens to achieve maximum performance is a topic of debate. This is likely influenced by other environmental factors such as humidity and wind speed, which can affect temperature fluctuations and the birds' responses to previous climate conditions. Chickens, regardless of their breed or age (broiler, pullet, or breeder), can tolerate a wide range of temperatures. However, exposure to high temperatures has been shown to decrease their production performance [17], and this effect can be intensified by higher relative humidity, which hampers evaporative cooling [32].

For day-old chicks, Ketelaars [16] recommended a temperature of 30–32°C at the bird's level. As shown in Table I.1, the temperature should be gradually lowered by 3–4°C until the chicks reach 4 weeks of age. Growing broilers, according to Daghir [19], thrive within a temperature range of 18–22°C. Holik [15] noted in earlier studies that birds are most comfortable when temperatures range between 18 and 24°C. However, the best performance in poultry production is ultimately determined by the market value of the product in relation to feeding costs.

The table below (Table 1) presents the recommended temperatures for poultry farming in the El-Oued region.

Table I. 1: Recommended temperature Schedule.

Age of chicken (week)	Température range (°C)
1	30-32
2	30-26
3	26-23
4	23-20
5	20

Maintaining the optimal production temperature in tropical regions is challenging, so it is essential for poultry house designers to carefully consider temperature fluctuations.

I.5.2 Relative humidity :

According to Oloyo [17], when internal temperatures exceed 26.7°C combined with high relative humidity, it significantly reduces feed efficiency, feather quality, pigmentation, and weight gain in chickens. Additionally, regardless of changes in relative humidity, the birds' performance was poor when internal temperatures ranged between 35°C and 37.8°C. This suggests that lower temperatures, along with higher humidity, may improve bird performance. However, humidity must be carefully managed, as it can create a conducive environment for microbes, increasing the risk of illness among the birds [18, 33].

Temperature and relative humidity are closely related. During the brooding period, especially in the early weeks, internal relative humidity may be low or excessively low due to the heat required for the chicks at that age or because they are thirsty or hatched in warmer conditions. As the chicks grow, the water vapor released during their evaporative cooling process to regulate body temperature causes internal relative humidity to rise rapidly [16]. Therefore, the third week and beyond are critical stages in chicken production, regardless of bird class.

Oloyo [17] also found that laying hens require relative humidity levels of 60–80% during the brooding phase and 50–70% after brooding for optimal performance.

I.5.3 Air composition :

The decomposition of bird feces generates harmful gases such as ammonia, carbon dioxide, methane, and hydrogen sulfide, which are detrimental to the health and performance of birds, the condition of cages, and the overall environment [16, 18, 34, 35, 36, 37, 38]. These gases are particularly concerning due to their negative effects. For optimal chicken production, it is recommended that ammonia concentrations should not exceed 25 ppm, and carbon dioxide levels should be kept below 2500 ppm [18, 39]. Regular removal of fecal waste from the poultry house is essential to reduce gas emissions and maintain the health and well being of the birds [17].



Figure I. 5: Air installation in poultry houses.

In an enclosed poultry house, the air composition can become hazardous if it is not regularly refreshed. Without proper ventilation, gases such as carbon dioxide, ammonia, and other harmful substances can reach dangerously high concentrations. Table I.2 outlines the critical and ideal levels of various gases as identified by research. The ventilation system plays a key role in exchanging the air within the building, supplying the oxygen necessary for the birds' survival and removing the toxic gases and odors produced by respiration and waste decomposition. Additionally, the ventilation system helps dilute airborne pathogens, keeping them at safe levels for the birds' health.

Table I. 2: Common gas levels in poultry houses.

Gaz	Symbol	Lethal	Desirable
Carbon Dioxide	CO ₂	Above 30%	Below 1%
Methane	CH ₄	Above 5%	Below 1%
Ammonia	NH ₃	Above 500ppm	Below 40ppm
Hydrogen Sulfide	H ₂ S	Above 500ppm	Below 40ppm
Oxygen	O ₂	Below 6%	Above 16%

Ventilation is essential for removing excess moisture from the poultry house. Effective ventilation reduces relative humidity, promotes better health, and prevents moisture buildup on walls and ceilings. As air is heated, its volume increases, enabling it to hold more moisture. For instance, when the air temperature rises by approximately 20°F, the moisture-holding capacity of the air doubles.

I.5.4 Air velocity :

Variable air velocity within the poultry house can help reduce high indoor temperatures to some degree. Additionally, air velocity plays a crucial role in convection cooling and maintaining air quality [5, 18]. In hot climates, it is recommended that the ventilation capacity be at least 5m³ per chicken per hour, with inlets providing an average of 1.5cm² per m³ of ventilation [16]. Hulzebosch [18] suggests that in temperatures ranging from 25 to 30°C, air velocity can be kept at 0.1–0.2 m/s. However, under the same temperature conditions, Lacy and Czarick [40] observed that broilers grew faster at air velocities of 2 and 3 m/s, respectively.

The effects of air velocity on chickens were further explored by considering their age within the temperature range of 25–30°C with varying air velocities. The research showed that increased air velocity (2 and 3 m/s) benefited 6-week-old broilers more than 4-week-old broilers. This could be attributed to the higher heat requirements of younger birds during the brooding period.

I.5.5 Lighting:

Lighting during the early stages of a bird's life has minimal to no effect on their hormonal system; its primary role is to stimulate activity, including feeding, growth, and both physical and physiological functions [15, 41, 42].

However, increasing the duration and intensity of light exposure can lead to negative outcomes such as fatigue, cannibalism, immune responses, limb deformities, and even death [41, 43, 44, 45, 46, 47].

A commonly used lighting schedule involves 16 hours of light followed by 8 hours of darkness, which has been shown to enhance overall poultry performance [15, 48, 49, 50]. Additionally, intermittent lighting—alternating short periods of light and darkness—has also demonstrated benefits in improving bird productivity [16, 51, 52, 53, 54]. During the post-hatch period (1–7 days old), a continuous lighting program with a minimum intensity of 20 lux is recommended to help chicks acclimate to their environment and encourage feeding [41]. After this stage, the light intensity is reduced to 3–5 lux, and an intermittent lighting system is introduced to better manage the birds' activity, thereby supporting improved performance and production [16, 41].



Figure I. 6: poultry house lighting.

Birds raised under yellow, green, and blue light sources tend to achieve higher body weights compared to those grown under red and orange light sources [55, 56, 57]. In their review, Lewis and Morris [55] observed that birds exposed to blue light were generally calmer, while those reared under red light displayed more active and aggressive behavior. Additionally, red light was shown to enhance sexual activity in birds.

I.6 Poultry housing system :

The type of poultry housing system used in chicken production plays a vital role and cannot be overstated. It protects the birds from extreme environmental conditions that could negatively impact their health and productivity. The total heat generated inside a poultry house comes from the birds themselves, the surrounding environment, and the decomposition of fecal matter [58, 59, 60].

Therefore, the choice of housing system is a key factor influencing the management approach used on the farm. In tropical regions, two common types of housing systems are the naturally ventilated open system and the mechanically ventilated open system, both of which are explored.

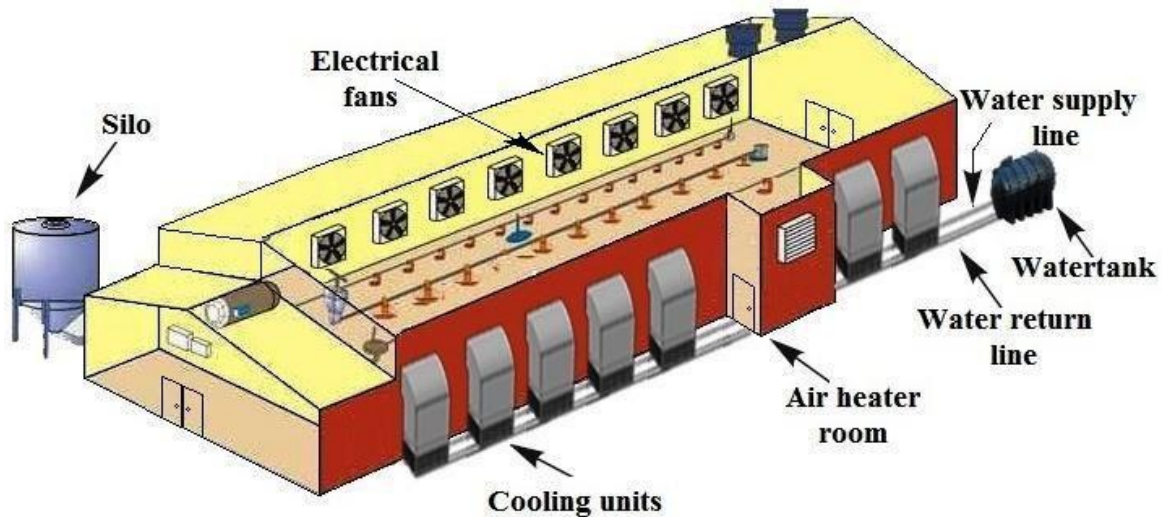


Figure I. 7: An illustration of the broiler poultry house.

I.6.1 Naturally ventilated open housing system :

The open poultry housing system is commonly used in tropical regions due to its simplicity, cost-effectiveness, and the ease with which heat can be regulated through natural ventilation [5, 32, 61]. However, this type of housing is susceptible to pests such as insects, rodents, wild birds, and other small predators, all of which can negatively affect the welfare, productivity, and performance of the chickens. To address these challenges, dwarf sidewalls are extended up to the roof eaves and covered with corrugated wire mesh to keep predators out. Additionally, a pesticide-filled gutter is often installed around the perimeter of the house to deter insect infestations. Key design considerations for optimizing performance and productivity in open poultry housing are outlined below.

I.6.2 Building orientation :

To minimize sidewall exposure to direct sunlight, poultry houses should be oriented in an east-west direction [5, 60]. This is important because direct solar radiation can intensify heat stress in

birds. While the deep litter system allows chickens to avoid direct sunlight, it can also cause them to cluster in specific areas of the house. This crowding can hinder effective cooling, potentially leading to stampedes or even fatalities [5].

I.6.3 House width, length and height :

While an east-west orientation helps reduce exposure to direct sunlight, it can also limit the advantages of prevailing east or west winds. To address this, Dagher [5] recommended that the width of the poultry house should not exceed 12 meters. This helps maintain a balanced air exchange rate and consistent temperature throughout the building.

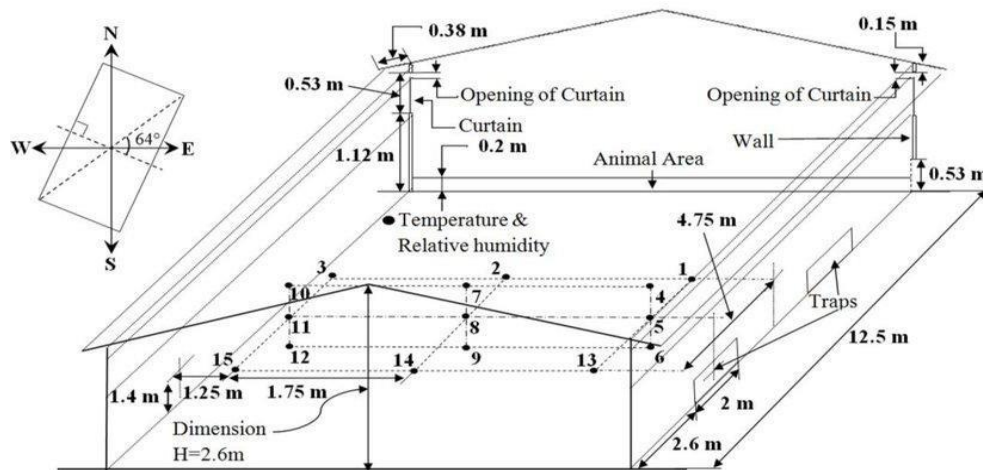


Figure I. 8: Dimensions and location of the poultry house building[5].

Moreover, the poultry house design should accommodate the routine activities and services carried out by farmers and professionals, such as bird transfer, feeding, beak trimming, waste disposal, and vaccination. When these tasks are performed manually, maintaining a long poultry house can become challenging. To enhance movement and service efficiency, doors should be installed every 15–30 meters [119]. According to Qureshi [32], in the case of battery cages, it is essential to consider the number of tiers being implemented. A two tier cage system allows for better air circulation within the building, while three and four tier systems may hinder airflow. As such, it is recommended that cage rows be limited to three, with central aisles no narrower than 1.2 meters and at least a 1 meter clearance between the top tier and the ceiling[120].

I.6.4 Roof slope:

A roof slope of 45 degrees is recommended as it helps minimize heat absorption from direct sunlight, increases the distance between the birds and the heat trapped beneath the roof, and facilitates rapid release of accumulated heat through a ridge vent. This design also enhances the air volume inside the structure, improving ventilation, and creates additional overhead space for installing equipment [5, 60, 62]. However, for insulated roofs, the required slope depends on the effectiveness of the insulation material used.

I.6.5 Roof overhang:

Roof overhangs can serve to shield a building's sidewalls from both direct and reflected solar radiation. The appropriate length of the overhang depends on the height of the sidewalls [2]. When correctly positioned at a roof slope of 45° [60], roof overhangs can reduce heat absorption by the sidewalls by approximately 30%.

I.6.6 Ridge opening:

Hot air naturally rises above cooler air due to differences in air density. Installing ridge vents in the poultry house can aid in ventilation by creating a stack effect. To ensure proper airflow and prevent inadequate ventilation, it is important to maintain an appropriate distance between buildings [2, 61]. However, ridge vents have been found to be less effective in insulated poultry houses due to the consistent temperature maintained inside [63].

I.6.7 Sidewall openings:

The sidewall consists of a permeable membrane, such as corrugated wire mesh, combined with an adjustable curtain, and is constructed up to the roof eave. A minimum height of 0.4 meters is recommended to safeguard the poultry house against water infiltration, direct and indirect sunlight, pests, and predators [2]. The corrugated wire mesh facilitates effective ventilation inside and outside the structure, while the adjustable curtain regulates airflow and airspeed. Additionally, the

curtain can be translucent or come in various colors to support the implementation of intermittent lighting systems [5, 15, 63].



Figure I. 9: Poultry sidewall inlets - wall vent poultry house ventilation.

I.6.8 Building obstruction:

Maintaining an adequate distance between buildings is crucial to ensure sufficient air exchange rates. Key factors influencing optimal spacing include wind speed, wind direction, and the surrounding topography. Nevertheless, the distance between poultry houses can be determined using the following equation provided by [63].

$$D= 0.4*H*L*0.5$$

Where:

- **D** represents the spacing between houses (measured from the ridge of the nearest wall of the adjacent building),
- **H** is the height of the neighboring structure, and
- **L** is the length of the neighboring structure.

Vegetation around the poultry house should be kept minimal and maintained at an average height to reduce the risk of wild bird nesting and the intrusion of rodents and other predators. Additionally, tree branches should be trimmed to roof eave level to prevent interference with airflow across the house [2].

I.6.9 Roof, end-wall and sidewall insulation :

In tropical regions, farmers have effectively constructed naturally ventilated poultry houses using locally available materials such as thatched roofs and bamboo [32]. For naturally ventilated poultry buildings, ceiling insulation should have a minimum thermal resistance (R-value) of 1.25 m²·°C/W. In areas where temperatures exceed 40°C, an R-value of at least 2.25 m²·°C/W is recommended [2]. There are various options for insulating a poultry house ceiling, including drop ceilings, rigid board insulation, spray polyurethane foam, and reflective insulation.

I.6.10 Cooling system :

Rooftop sprinklers have proven effective in significantly reducing roof temperatures [5, 60]. However, the roofing material selected must be capable of withstanding constant exposure to water [2]. During hot weather, fogging systems can help enhance evaporative cooling for poultry by generating a fine mist under high pressure, which helps keep the birds cool. Still, it's essential to regulate the indoor humidity, as excessive moisture combined with high temperatures can negatively affect bird health [5, 60].

To further mitigate heat stress, circulation fans are used to increase air velocity, enhancing convective cooling. Typically, these fans generate air speeds of at least 0.5 m/s and effectively ventilate an area equivalent to 15 times their horizontal diameter and 5 times their vertical diameter [5]. For best performance, they should be installed 1–1.5 meters above the floor and tilted downward at a 5° angle.

I.6.11 Vegetation :

Shrubs and grasses contribute to reducing both reflected and direct solar radiation through shading and convective cooling [60]. To deter pests and predators, it is important to keep the vegetation well maintained and trimmed [2]. Additionally, planting tall trees along the sides of the poultry house can create a natural canopy that protects the sidewalls from direct and reflected sunlight during the hottest parts of the day.

I.7 Open housing system with mechanical ventilation :

The use of mechanically ventilated housing systems arose from the need to maintain suitable indoor environmental conditions for optimal bird performance during extreme weather. Mechanical ventilation offers greater control over air exchange, airflow velocity, and direction [2, 16]. These systems typically operate using either positive or negative pressure.

The most common type, the negative-pressure system, functions by using fans to expel air from the building through a designated air inlet system. This process creates a low-pressure environment inside, causing fresh air to enter through the same inlets [2].

Negative-pressure systems can be implemented using inlet or tunnel ventilation. Inlet ventilation features a uniform distribution of exhaust fans and air inlets throughout the house. In contrast, tunnel ventilation places exhaust fans at one end and air inlets at the opposite end, thereby enhancing airspeed and promoting more efficient air exchange [2].

I.7.1 Building a poultry houses :

Housing plays a crucial role in poultry farming, and many producers often ask how to properly construct a poultry house. Essentially, proper housing is key to maintaining bird health, encouraging rapid growth, and maximizing productivity [5]. The structure should be well-insulated and securely built to ensure effective ventilation management [2].

Instead of solid walls, insulated movable curtains can be used on the sidewalls during colder seasons or power outages. However, it's important to note that while movable curtains offer flexibility, solid walls generally provide superior insulation.

The floor of the house should be made of concrete and must be both rat-proof and moisture-resistant. To further prevent rodent and snake intrusion, the concrete floor should extend about 1.5 feet beyond the wall on each side. For deep litter systems, doors should open outward and measure at least 6 feet by 2.5 feet in size. The image below illustrates the geometric and structural design of poultry houses (Figure I.10) [65].

Here are some essential guidelines for constructing an effective poultry housing system:

- The poultry house must be well ventilated to ensure healthy air circulation.
- Allow ample sunlight and fresh air to enter the building.
- Ideally, the house should be oriented from north to south for better exposure and temperature regulation.
- When constructing multiple houses, maintain a spacing of approximately 12 meters between each unit.
- Thoroughly clean the house before introducing the birds.
- Create a deep litter system and keep it consistently dry and clean.
- Arrange feed and feeding equipment at appropriate intervals based on the number and needs of the birds.
- It's best to build the poultry house in an open, well aerated area [65].

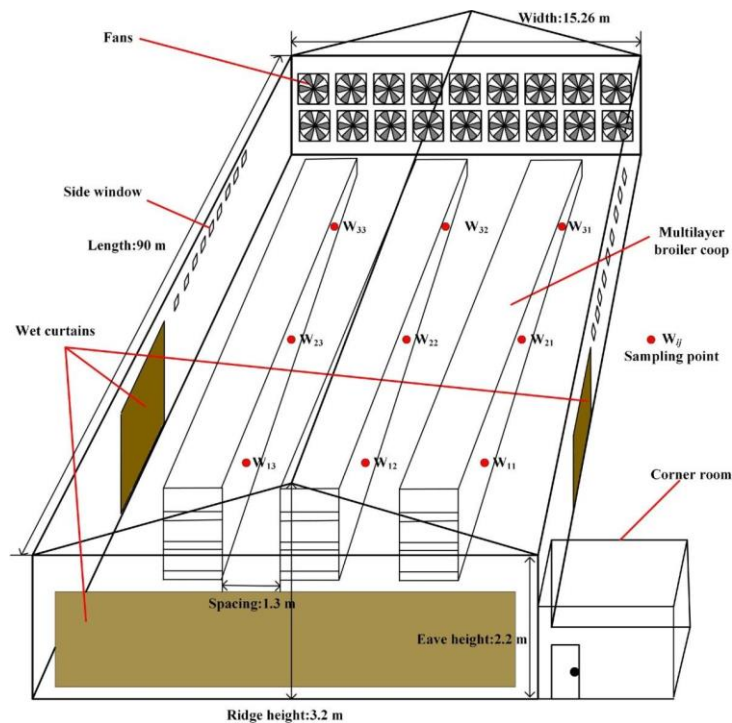


Figure I. 10: Building poultry houses[65].

I.7.2 Exchange of air :

The combination of high external temperatures and the heat generated by activities within the poultry house increases the temperature of the indoor air. To maintain the indoor temperature within 2.8°C of the outdoor air temperature, a properly functioning mechanical ventilation system must quickly exchange the air. The following formula can be used to calculate the appropriate size of the exhaust fan needed for effective ventilation [2].

$$\text{Building surface heat}(w) = \frac{A}{R} * (T_o - T_i)$$

Where:

- **A** represents the size of the building surface (m²)
- **R** is the insulation value of the wall material (m²·C/W)
- **Outside temperature** (°C) refers to the ambient external temperature
- **Inside temperature** (°C) is the indoor temperature
- **To** is the maximum exterior temperature that is not influenced by external environmental factors.

When calculating heat gain for a roof in a building with attic space, the **To** value for ceilings with insulation directly under the roof is considered to be 65°C [2]. To ensure bird comfort, the **Ti** value should be considered to be 27°C. The cumulative insulation value of the wall segment is equal to the **R** value.

The total heat produced (both sensible and latent) in commercial broilers is 7.9 W/kg, while for broilers, pullets, and broiler breeders, it is 5.1 W/kg [2, 64]. The heat generated by the birds can be expressed as shown below [2].

$$\text{Bird heat } (w) = \text{sensible heat } (W/kg) * \text{weight of the bird } (kg)$$

50 percent of the total heat produced by birds is sensible heat.

$$\text{Total heat } (W) = \text{building surface heat } (W) + \text{bird heat } (W)$$

However, the air movement capacity required to maintain a temperature difference of

2.8°C between intake and exhaust air is shown below.

Air capacity (m³/h) = total heat (W) * 3.4/2.8°C

I.7.3 Air inlet system :

The extraction of air from the poultry house creates negative air pressure inside, causing fresh air to automatically flow in through designated openings. The speed and volume of the incoming air depend on the amount of air being removed. Negative-pressure air intake pipes are used to manage the internal climate by controlling the location, speed, and direction of fresh air entry. Meanwhile, the exhaust fan regulates the volume of air entering the building. Figure I.11 illustrates this system. The exhaust fan(s) in the poultry house create a slight vacuum, allowing air to flow into the barn through the designated inlets.

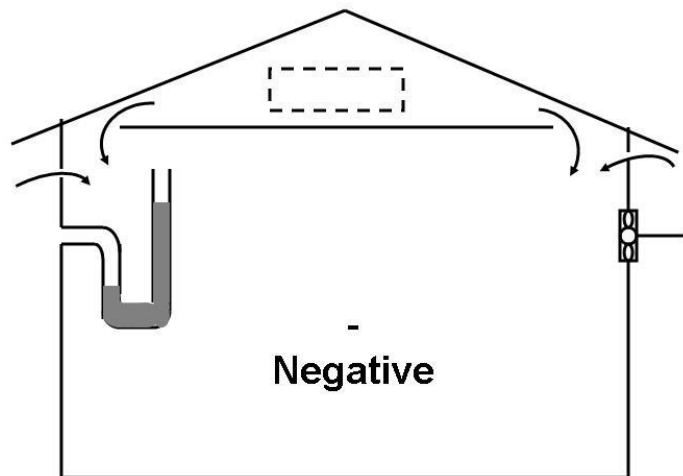


Figure I. 11: Negative-pressure air intake pipes[2].

I.7.3.1 Inlet speed :

The speed of fresh air entering the poultry house is influenced by the pressure difference between the interior and exterior environments. This pressure difference is determined by the number and size of the air inlets. By controlling this pressure differential, the airflow pattern inside the building, as well as the negative-pressure air intake pipes used to regulate the internal climate, can also be controlled.

I.7.3.2 Inlet area :

The exhaust fan should generate a static pressure of approximately 12–25 Pa to ensure effective control and distribution of air throughout the poultry house.

I.7.3.3 Air inlet control :

The design of air inlets should be strategically positioned, as the direction of airflow is influenced by external weather conditions, as well as the age and class of the chickens. During the colder months, air inlets should direct air toward the ceiling, while in hotter months, the airflow should be directed towards the floor.

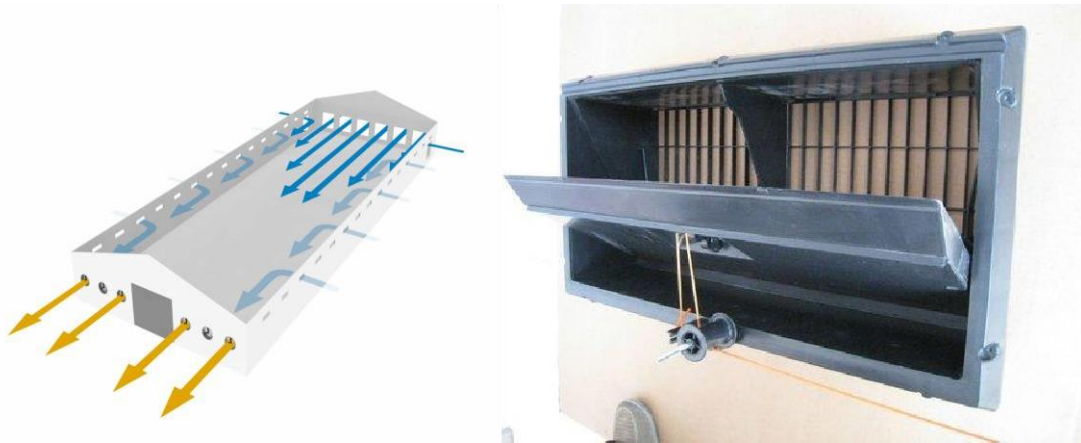


Figure I. 12: Air inlet control in poultry houses.

I.7.4 Types of inlet ventilation system :

I.7.4.1 Cross ventilation :

The exhaust fans are located on one side of the poultry house, with the air intake pipes positioned on the opposite side. This setup is ideal for smaller poultry houses (less than 10 meters) as it may create uneven environmental conditions in larger buildings [2].

I.7.4.2 Ventilation via the sidewall :

Exhaust fans are installed on both sides of the building walls, below the air intake pipes. The distance between the exhaust fans and the intake pipes should be at least twice the diameter of the fan. The exhaust fans draw air through the floor, directing it towards the center. This setup is also suitable for houses with a maximum width of 12 meters [2].

I.7.4.3 ventilation attic inlet :

In this ventilation setup, exhaust fans are positioned low on the walls, while air inlets are located in the ceiling. This design requires proper ceiling insulation and is particularly effective in hot climates. It is a highly recommended ventilation method for raising laying hens [2].

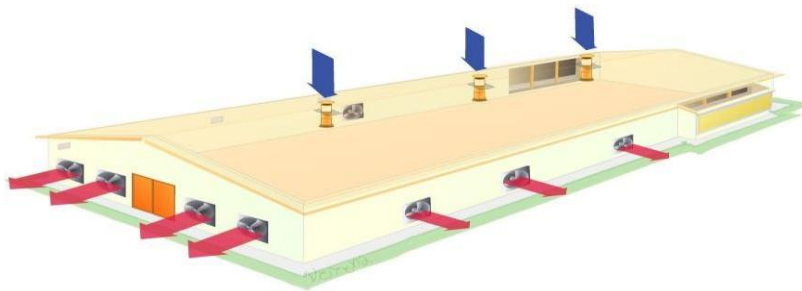


Figure I. 13: Overhead ventilation in poultry house.

I.7.5 Air movement inlet ventilated house :

The exhaust fans are positioned on the lower sides, and the air inlets are located in the ceiling. This ventilation system requires proper ceiling insulation and is most effective in hot climates. It is a highly recommended method for raising laying hens [2].

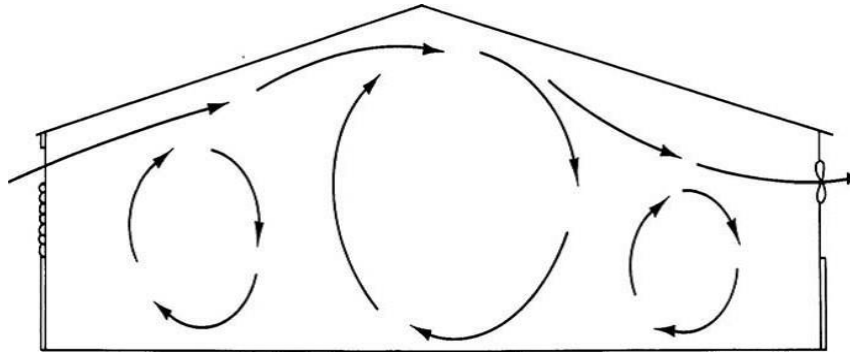


Figure I. 14: Air movement inside the poultry house.

I.7.6 Tunnel ventilation system :

The tunnel ventilation system is designed to ensure the appropriate air velocity and exchange rate. However, the required air speed depends on the specific type of bird being raised. Table 2 outlines the recommended air velocities for different types of poultry [2].

Table I. 3: Air velocity recommendations for tunnel-ventilated dwellings.

House type	Air speed (m/s)
Broilers	2.5–3
Pullets	1.75–2.25
Broiler breeders	2.25–3
Commercial layer	2.5–3

I.7.6.1 Tunnel fan capacity and air velocity :

The capacity of the tunnel fan is calculated using the same method as the inlet ventilation system. However, unlike the inlet system which relies on a circulating fan to maintain adequate air velocity the required average air velocity inside the tunnel house is determined using the formula below [2].

$$\text{Air velocity tunnel fan capacity} / (\text{cross sectional area of the house}) \times 3600$$

Where:

- Air velocity (m/s)
- Tunnel fan capacity (m³/h)
- Cross-sectional area (m²)

However, it is important to note that the cross-sectional size of the house negatively affects airspeed. Therefore, long and narrow houses with lower ceilings are recommended [2]. Consequently, the following equation can be used to determine the required air velocity.

$$\text{Tunnel fan capacity} = \text{desired air velocity} / (\text{cross-sectional area of the house}) \times 3600$$

Where:

- Desired air velocity (m/s)
- Tunnel fan capacity (m³/h)
- Cross-sectional area (m²)

In situations where space is limited, air deflectors with a large cross-sectional area can be installed to reduce the effective cross-sectional area inside the poultry house. These deflectors are curtain-like structures that extend 2.5–3 meters from the ceiling toward the floor. Research has shown that air deflectors can increase air velocity for a range of 1.2 meters upwind and 6–9 meters downwind. However, to prevent disruptions in fan performance and air exchange due to increased static pressure, deflectors should be installed at a minimum height of 2.5 meters above the ground [2].

I.7.6.2 Air velocity distribution :

Air velocity in a tunnel house is generally assumed to be uniform throughout. However, it can vary slightly due to factors such as the smoothness of building surfaces, the presence of poultry equipment, and other obstacles that deflect airflow. The difference in air velocity between the center and the sides of the house can range from 15% to 40% [5].

I.7.6.3 Bi-directional tunnel house :

To achieve maximum air speed in a tunnel house, it is advisable to place the fans at one end and the air intake at the opposite end. However, if the poultry house exceeds 180 meters in length and the required air velocity in a single direction is more than 3.5 meters per second, a bi-directional tunnel ventilation system should be implemented. In this setup, fans are installed on the end walls of the building, and the air intake is located in the center. To ensure a consistent temperature difference between the intake and the fans, the air velocity in both directions is reduced to half of the required velocity, while still maintaining the same air exchange rate [5].

I.7.6.4 Tunnel fan placement :

Fans can be installed either on the end walls or on the side walls near the ends of the building, and their performance remains largely unaffected by their placement. However, as the width of the poultry house increases, placing fans on the side walls may lead to the formation of dead zones with reduced airflow.

I.7.6.5 Tunnel inlet opening :

If evaporative cooling pads are not used, it is recommended that the intake area be at least 10% larger than the cross-sectional area of the house. For tunnel houses equipped with evaporative cooling pads, the intake size depends on the type of pad used. It is also advised to position the intake opening on the sidewall as close to the end wall as possible. However, if the house is wider than 15 meters, the inlet ports should be installed on the end wall [2].

I.7.6.6 Cool weather inlet system for tunnel ventilated houses :

Using a tunnel ventilation system is recommended during hot weather, as cooler conditions tend to decrease the air exchange rate. Therefore, it is suggested that the existing intake system be capable of handling at least 60% of the tunnel fan capacity before transitioning to tunnel ventilation. This allows for easier switching between systems during cooler weather [2].

I.7.7 Poultry exhaust fans :

I.7.7.1 Types of fans :

I.7.7.1.1 Exterior and interior shutter fans :

This is the simplest type of exhaust fan. When not in use, its shutters remain closed. However, an external shutter can hinder airflow, as air tends to spin off the blades upon contact. In contrast, fans with internal shutters have them positioned on the intake side, which minimizes airflow obstruction. These fans also feature larger shutters, allowing for greater air movement. According to Dagher [2], this design improves airflow by 5–10% compared to fans with external shutters.

I.7.7.1.2 Discharge cone fans :

It improves fan performance by 5–10% by making the transition from drawing to fans easier [5].

I.7.7.1.3 Belt-drive fans :

A simple pulley mechanism drives the fan blades. To avoid belt slippage, it may be updated with an automated belt tensioner [5].

I.7.7.1.4 Direct-drive fans :

The blades of the fan are directly linked to the motor shaft, avoiding the need for a belt. In comparison to belt-driven fans, they are less energy efficient [2]

I.8 Conclusions :

This chapter reviews and synthesizes existing literature on broiler chickens and their housing systems, underscoring the pivotal role of environmental design in enhancing bird performance, welfare, and overall productivity. The analysis concludes that heat loss in birds occurs through convection, radiation, and conduction only when ambient temperatures are below or within their thermoneutral zone. In tropical regions, the design of open, well ventilated housing has been explored to create optimal environments for broiler production. Research indicates that heat loss in birds is amplified with increased air volume and velocity.

Attention to architectural elements such as building orientation, roof slope, roof overhang, landscaping, building height, width, and length is essential for effective housing design. It is evident that structures incorporating natural ventilation are critical for achieving successful broiler production. Additionally, integrating cooling mechanisms such as fogging systems, sprinklers, and circulating fans into naturally ventilated housing systems has been shown to enhance bird performance significantly.

In situations where environmental temperatures are excessively high and unbearable for birds, mechanically ventilated open housing systems have been introduced. These systems, particularly tunnel and intake ventilation designs, have proven effective in sustaining productive broiler farming even under harsh climatic conditions. However, designing an efficient mechanically ventilated house requires careful consideration of several factors, including fan capacity, heat generated by the birds, inlet sizes, installation levels, positioning of inlet pipes and exhaust fans, and the capacity of circulation fans in inlet-ventilated systems. Proper planning and execution of these elements are vital to ensuring optimal performance and welfare of broilers in challenging environments.

Chapter 02

Methodology

II.1 Introduction :

Poultry farming is an energy-intensive industry that requires substantial energy inputs to maintain an optimal indoor environment conducive to bird health and high productivity in meat and egg production. The need for heating during colder months, cooling and ventilation during hot periods, and consistent lighting makes energy demand continuous and critical. In response to rising energy costs and environmental concerns, numerous studies and practical applications have focused on integrating renewable and sustainable energy technologies into poultry farming. These technologies include photovoltaic (PV) systems, solar thermal collectors, hybrid photovoltaic/thermal (PV/T) systems, thermal energy storage, ground, air, or water source heat pumps, as well as advanced lighting and radiant heating solutions. Compared to conventional poultry houses, these modern systems have demonstrated the ability to reduce energy consumption by up to 85%, with estimated payback periods ranging from 3 to 8 years.

Among the most promising developments is the emergence of Hybrid Renewable Energy Systems (HRES), which combine multiple energy sources to meet both thermal and electrical demands more efficiently. A particularly effective configuration is the integration of solar photovoltaic systems with geothermal technologies, such as Earth-Air Heat Exchangers (EAHE). This hybrid approach leverages the abundant solar irradiance in regions like Algeria to generate electricity during the day, while geothermal systems provide stable, passive heating or cooling by utilizing the relatively constant subsurface temperatures. The synergy between these two sources creates a resilient, cost-effective energy system that reduces dependence on fossil fuels, enhances system reliability, and ensures optimal indoor climate control in poultry houses.

In this chapter, we will provide a detailed analysis of energy-saving heating, ventilation, and air conditioning (HVAC) systems in poultry farming. We will also estimate the energy requirements of broiler chickens based on their growth cycle, activity levels, and seasonal breeding conditions. Particular focus will be given to the application of these systems within the Algerian context, and especially in El Oued Province, where extreme temperature variations and high solar potential make the use of solar-geothermal hybrid systems especially advantageous. This review

aims to identify the most effective strategies for improving energy efficiency, reducing emissions, and enhancing sustainability in modern poultry production.

II.2 Poultry production in Algeria :

The Algerian poultry industry produces an annual average of 340,000 tons of white meat and over 4.8 billion eggs. The sector involves approximately 20,000 farmers and provides employment for about 500,000 people. However, it depends heavily on imported inputs, with 80% of its 2.5 million tons of poultry feed - mainly consisting of corn and soybean meal as well as three million breeder birds, veterinary products, and equipment being sourced internationally. This reliance on foreign markets, particularly for corn and soybean meal which constitute more than 75% of poultry feed, represents the primary constraint on the industry's development.

The current organization of Algeria's poultry sector originates from government development policies implemented in the 1980s. Today, producers face numerous challenges including supply chain issues, rising costs, reduced state involvement, and difficulties in marketing their products. These problems have led many experienced farmers to leave the industry, resulting in a significant loss of expertise. Simultaneously, the sector is undergoing modernization to meet international standards, particularly in preparation for Algeria's expected accession to the World Trade Organization (WTO) and its partnership agreement with the European Union. This integration will lead to increased competition and requires enhanced cooperation between various stakeholders (professional organizations, inter-professional associations) and relevant government agencies (industry, agriculture, and trade ministries). Establishing an appropriate institutional framework is crucial for developing, implementing, and monitoring policies for the poultry meat and egg sectors[66].

The global emergence of avian influenza (H5N1 virus) also affected Algeria's poultry production, despite no cases being detected in the country. White meat production decreased significantly by 15.5% in 2005 compared to 2004[68] (Figure II.1), though it rebounded sharply in 2006 with a 68% increase to reach 241,166 tons[68]. During the avian flu crisis, approximately 80% of Algeria's 20,000 poultry producers temporarily ceased operations[67].

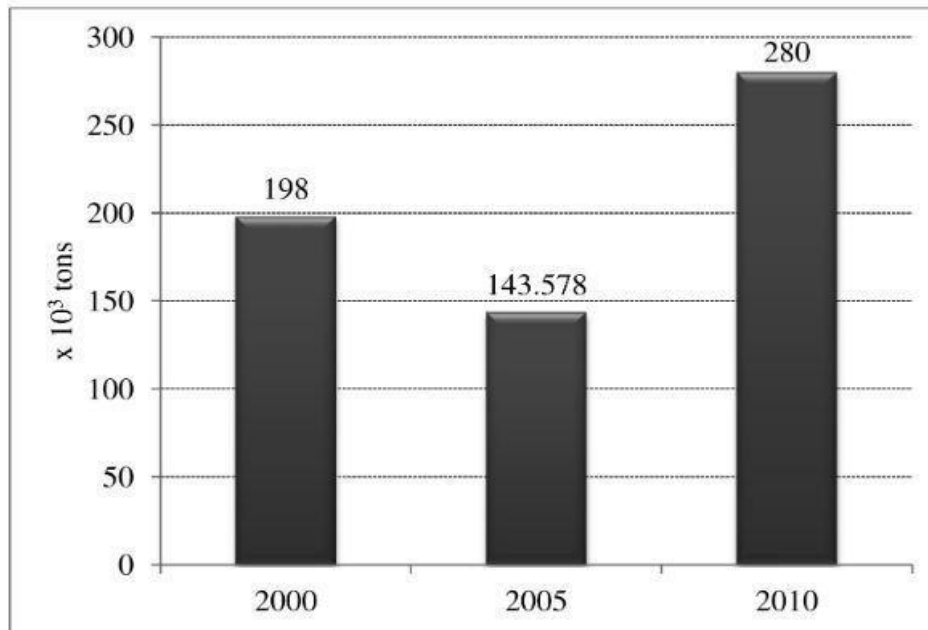


Figure II. 1: Evolution of white meat production in the last decade [69].

II.3 Geothermal energy

refers to the heat that comes from deep within the Earth. The term “geothermal” combines two Greek words: *geo*, meaning earth, and *therme*, meaning heat. Since the Earth's interior continuously produces heat, geothermal energy is classified as a renewable resource. This natural heat is utilized for various purposes, including residential heating and electricity generation.



Figure II. 2: Geothermal energy.

Geothermal energy stands out as one of the most energy efficient technologies available today, offering the following advantages:

- effective for both heating and cooling livestock sheds.
- near-zero carbon footprint.
- easily scalable for various applications.
- has the potential to reduce energy bills by 50% to 70%.
- delivers consistent base-load power, unaffected by weather conditions like sun or wind.

Geothermal heating and cooling involves utilizing the constant underground temperature found at depths of two to three meters to regulate indoor temperatures [103].

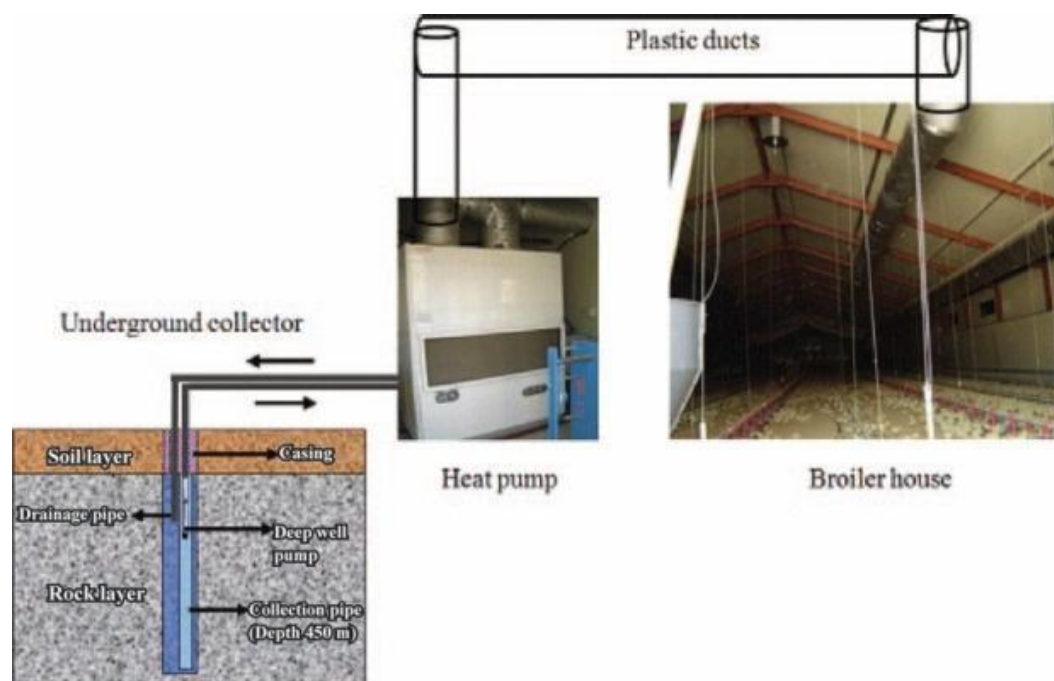


Figure II. 3: Schematic diagram of the geothermal heat pump (GHP) system for the broiler house [103].

II.3.1 Working principle of geothermal energy:

In Algeria, depending on the location, the soil temperature at a depth of two to three meters remains relatively constant throughout the year, typically ranging from 22°C to 24°C. Geothermal heating and cooling systems use a closed-loop network of underground pipes filled with fluid to tap into this thermal energy. The ground loop collects heat from the earth and transfers it to a heat pump. This pump amplifies the heat and distributes it throughout the poultry house, while also

extracting excess warmth from the interior and channeling it back into the ground through the same loop system [105].

II.3.2 The main components of a geothermal energy system :

II.3.2.1 The heating and cooling pump :

A heat pump is an electrically operated system that moves heat from a cooler area (the source) and transfers it to a warmer area, such as poultry houses. The same principle is used in cooling mode, where the system removes heat from a warmer zone (the ground) and transfers it to a cooler space [89].

Ground-source heat pumps consist mainly of two essential components: a ground heat exchanger and a heat pump unit. Unlike air-source heat pumps, which feature an external heat exchanger, ground-source systems incorporate the heat exchanger inside the building [118].

II.3.2.2 Ground heat exchanger :

- **Open Loop :**

In an open-loop system, a groundwater bore serves as the primary heat source. Groundwater is pumped into the heat pump unit, where heat is extracted before the water is safely discharged in an environmentally responsible way. These bores are highly effective sources of thermal energy, as groundwater typically maintains a consistent temperature year-round [101].

Open systems utilize the thermal energy stored in underground water bodies. Water is drawn from a well and directed straight to the heat exchanger, where the heat is extracted. Afterward, the water is discharged into a surface water body, as illustrated in Figure II.4 [101].

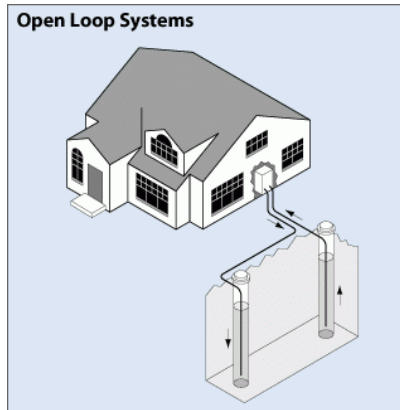


Figure II. 4: open loop system[101].

- **Closed Loop :**

A closed-loop system utilizes a continuous circuit of underground polyethylene (poly) piping. This pipe network is linked to the indoor heat pump, forming a sealed loop below the surface that circulates a mixture of water and environmentally safe antifreeze. Unlike open-loop systems that rely on groundwater from a bore, closed-loop systems continuously recirculate their heat-transfer fluid within a pressurized, closed-loop environment [80].

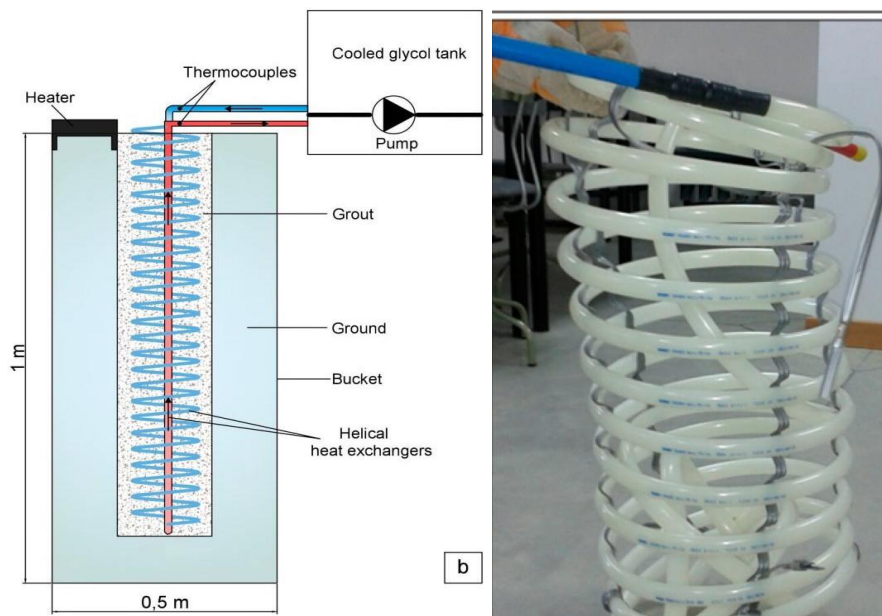


Figure II. 5: spiral closed loop system [80].

II.4 VENTILATION PRINCIPLES :

II.4.1 Economic importance of ventilation :

Modern broiler chickens have undergone significant genetic improvements to meet market demands, resulting in accelerated growth rates and enhanced carcass yields. However, these advancements particularly the increased breast muscle development have also made the birds more vulnerable to environmental stressors such as heat, ammonia, and airborne particulates.

Current research indicates that a substantial portion of performance variation among broiler flocks can be directly linked to the effectiveness of environmental management systems. Precise regulation of two key factors proves critical:

1. Temperature control
2. Air quality maintenance

These findings underscore the heightened importance of optimized housing conditions in contemporary poultry production systems.



Figure II. 6: Ventilation in poultry houses.

The broiler industry's primary goal is efficient production of market-ready chicken meat. Achieving this requires meticulous maintenance of optimal housing conditions, as environmental factors directly impact:

- Flock health status
- Target live weights
- Feed conversion efficiency

- Carcass quality and yield

Suboptimal temperature and air quality control negatively affect all these parameters, ultimately reducing profitability. The difference between mediocre and exceptional flock performance often lies in environmental management.

Modern broiler genetics have been developed for rapid growth, but this potential can only be realized through consistent feed intake. Elevated temperatures suppress appetite, limiting consumption and growth. Therefore, maximizing genetic potential fundamentally depends on advanced ventilation systems that maintain ideal in-house conditions.

II.4.2 Air quality :

Air consists primarily of nitrogen, oxygen, and carbon dioxide, with water vapor constituting less than 1% of its composition. Despite its minimal proportion, water vapor plays a critical role in determining air properties due to its biological importance and exceptionally high latent heat capacity - the substantial energy required to transform water from liquid to vapor state. This characteristic means the small amount of water vapor present often contains most of the air mixture's total heat energy. In poultry housing environments, air quality deteriorates when contaminants exceed acceptable thresholds. These pollutants include solid particulates, microorganisms (bacteria, fungi, and viruses), and harmful gases like ammonia, hydrogen sulfide, and carbon dioxide. While these contaminants are naturally present to some degree, their concentrations can be effectively managed through proper environmental control systems to maintain optimal poultry house conditions.

II.4.3 Natural ventilation :

Natural ventilation, as the term suggests, is a technology that utilizes natural forces to supply fresh air to poultry facilities. Air is exchanged through the structure's inlets and outlets. It is essential to understand the distinctions between natural and mechanical ventilation systems. In mechanical ventilation systems, air exchange fans can be adjusted to achieve the desired rate of air exchange. Both thermal buoyancy and wind are influenced by unpredictable weather changes, which differentiates natural ventilation control [74].

This system operates in "single-sided open," "curtain-sided," or "natural" buildings. Fans may also be used inside the structure to circulate air. Figure II.7

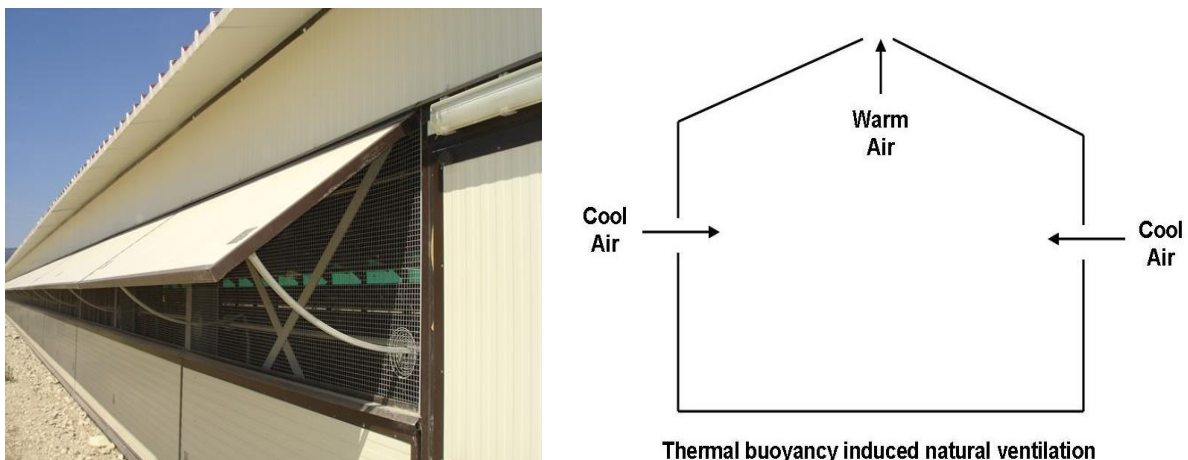


Figure II. 7: Ventilation Natural.

II.4.4 Electric ventilation :

Enclosed or climate-controlled buildings typically feature solid side walls or curtains that remain closed during operation. As a result, electric ventilation systems and fans are employed to circulate air within the building. Figure II. 8



Figure II. 8: Electric ventilation.

II.5 The main factors and ingredients in raising chickens :

II.5.1 temperature :

Chicks require warmth, but this need decreases gradually as they grow. Table 2 shows the ideal nursery temperature based on the age of the chicks. The actual temperature should not differ from the ideal temperature by more than 2°C.

Table II. 1: represents the optimum temperature for broiler chickens.

Chickage (number of days)	Temperature under the heater	Temperature in the poultry house
1	35 C °	27C °
2→10	32 C °	26C °
11→14	30 C °	25 C °
15→ 17	29 C °	24 C °
18→20	27C°	23C °
21→24	26 C °	22 C °
25→27	25 C °	22 C °
28→31	23 C °	21 C °
34→37	21 C °	20 C °
38→40	20 C °	19 C °
41→45	18 C °	18 C °

II.6.2 Humidity and litter :

The litter should always be kept clean and dry, as wet litter poses a significant risk to bird health. Characteristics of good litter include:

- Made of sawdust (mature) or rice husk;
- Clean, dry, and slightly elastic, not sticking excessively to hands or shoes;
- A thickness of 8 cm during the first week of a bird's life, reducing to about 6 cm thereafter;
- Warm to the touch by the time birds reach 11 days old, as the litter generates heat from decomposition;
- Maintained clean and dry, especially when considering a density of 10 birds/m²;
- If the litter becomes wet or sticky in the entire house or in certain areas, it indicates a problem that needs addressing;
- Litter near feeders should be removed if mixed feed is present in it. Otherwise, chickens may consume grain scattered outside the feeder along with the litter, leading to digestive issues and diarrhea.



Figure II. 9: Wood carpentry in the poultry house.

The capacity of air to hold varying amounts of water vapor, expressed as relative humidity, is another critical factor that significantly impacts pathogen growth and litter conditions. While humidity does not directly affect chicken behavior, it can lead to indirect issues. For instance, during dry weather, low humidity causes dust accumulation, which irritates the respiratory system and facilitates the spread of bacterial infections. Conversely, a damp environment makes chickens more susceptible to cold stress, especially at lower temperatures, and promotes the formation of crusts on the ground, increasing the risk of germs and parasites. The ideal relative humidity for raising chickens ranges between 40% and 75%; however, deviations from this range may lead to health problems, such as respiratory diseases [75].

Table II. 2: represents the optimum humidity for broiler chickens.

Chickage (number of days)	Humidity in the poultry house
1	62%-60%
7	60%-50%
14	50%-46%
21	46%-40%
28-45	40%

II.5.3 Lighting :

Light is a crucial factor that supports animal growth, as it enables continuous feeding. Proper lighting management in poultry houses is essential for optimal performance.

- From 1 to 15 days: 3–5 W/m² for 24 hours.
- 3–4 weeks: 1–2 W/m² for 10–14 hours per day [76].

During the first two days, maximum lighting (23–24 hours) with an intensity of approximately 5 W/m² is critical to encourage water and feed intake. The purpose of this lighting is to help chicks locate feeders and drinkers. However, excessively bright lighting in hot areas should be avoided to reduce stress. Nighttime lighting during cooler periods is necessary to maintain proper consumption levels. To minimize activity and promote growth, broilers should be kept in semi-darkness.

Various light sources can be used for broilers (Fig II.9). The most common types include incandescent, fluorescent, and LED lighting:

- Incandescent lamps provide a good spectral range but are not energy-efficient [77].
- Fluorescent lamps are more efficient than incandescent lamps but lose intensity over time and must be replaced before complete failure.
- LED lights (Light Emitting Diodes) are highly efficient, offer customizable color options, and have a longer lifespan, though their initial cost is higher [78].



Lamp Halogen 45w



lamp fluorescent 16w



lamp LED 6w

Figure II. 10: Types of light sources that can be used for broilers.

Low light intensity during the day (overly dim lighting) can negatively impact mortality rates, growth, and overall broiler welfare. Insufficient lighting may also result in:

- Impaired eye development.
- Increased risk of foot injuries.
- Reduced activity levels and altered resting behaviors, such as decreased dust bathing and scratching.
- Disruption of physiological rhythms, as birds may struggle to distinguish between night and day [79].

Table II. 3: Lighting Program Recommendations.

Chicken age (in days)	Duration of the light period
1 to 4	24 hour
5 to10	22 hour
10 to the end.	24 hour

II.5.4 Heating equipment:

- **Electric brooder :**

It consumes less fuel, offers a wide range of applications, and is easy to adjust and maintain.



Figure II. 11 : Electric chicken heater.

II.6 The identification of traditional and modern poultry farmers :

It is widely recognized that poultry farming in Algeria has gained significant attention across all regions of the country. The practices in poultry farming range from traditional to modern methods, and this is where the key distinction lies. Traditional methods lack even the most basic

modern and advanced tools used in poultry houses, such as heating, ventilation, air conditioning, and lighting. On the other hand, modern methods are defined by the use of advanced technology in chicken rearing, enabling farmers to achieve higher productivity and superior quality compared to traditional practices.



Figure II. 12: traditional and modern poultry farmers.

II.6.1 The location of the poultry house where the study was carried out :

The study area is situated in the southeastern part of the country, approximately 670 kilometers away from the capital, Algiers. It is geographically located between latitudes 33° and 34° north and longitudes 6° and 8° east, within the northern desert region of the eastern race. The study focuses on the municipality of Oued El-Alanda.



Figure II. 13: Location of El-Oued Province in Algeria.

II.6.2 Breeders ages in Oued Souf :

It has been observed that 2% of traditional poultry farmers are 55 years old, while 13% represent other age groups. On the other hand, the data indicates that most poultry farmers fall within the ages of 28, 35, 44, 53, 65, and 70 years. Notably, 33% of breeders are over 45 years old [23].

II.6.2.1 level of poultry farmers :

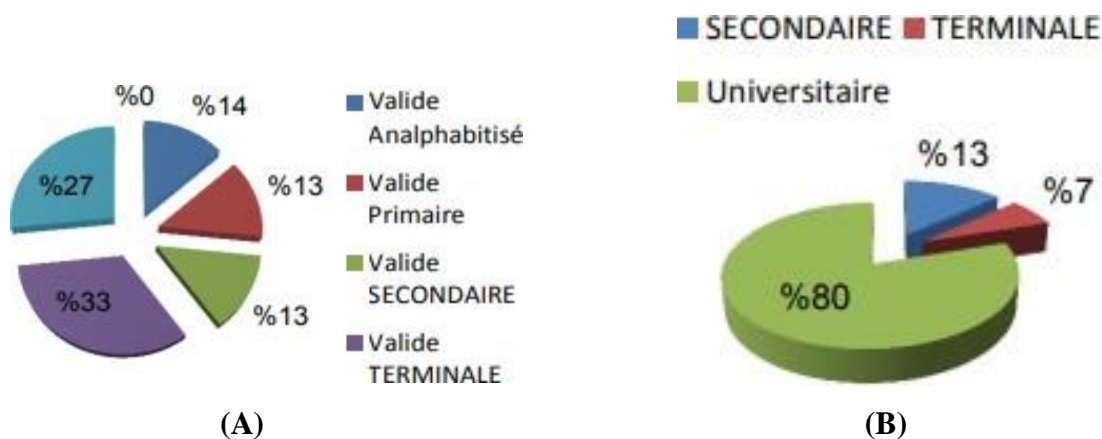


Figure II. 14 : (A) Traditional poultry farmers. - (B) Modern poultry farmers.

The figure above illustrates that 27% to 33% of poultry farmers possess a terminal or university-level education. Conversely, there is a percentage range of 14% to 13% of poultry farmers who are illiterate or have only primary or secondary education, respectively. Figure II.14

further highlights that 80% of poultry farmers have attained a university-level education, while 7% have a terminal-level education.

II.6.2.2 Poultry farmer's adjectival :



Figure II. 15 : (A) Traditional poultry farmers - (B) modern poultry farmers.

The data shows that 60% of poultry farmers own traditional poultry houses, while 40% are tenants. In contrast, for modern poultry houses, 80% of poultry farmers are owners, and 20% are tenants.

II.7 Poultry building characteristics

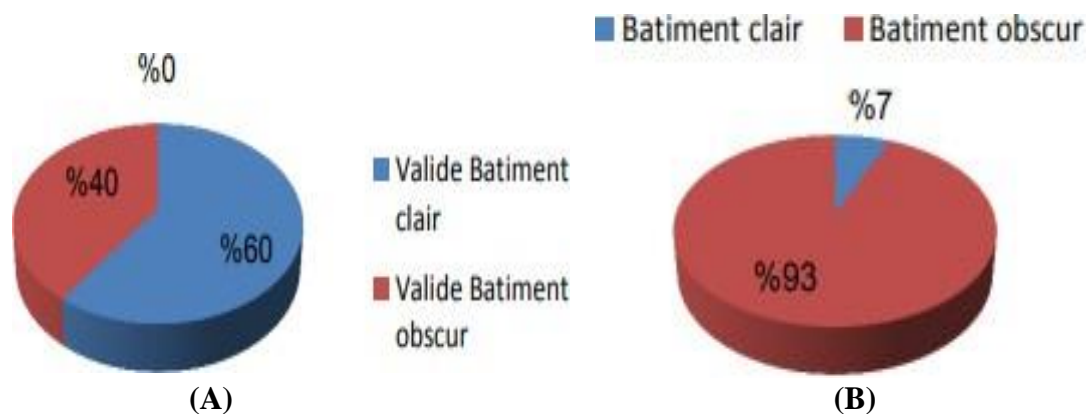


Figure II. 16 : (A) Type of traditional building - (B) Type of modern building.

(A) shows that (60%) type of traditional buildings are dark than (40%) are light.

The graph in (B) shows that 93% of typical modern buildings are dark.

II.7.1 Capacity of buildings:

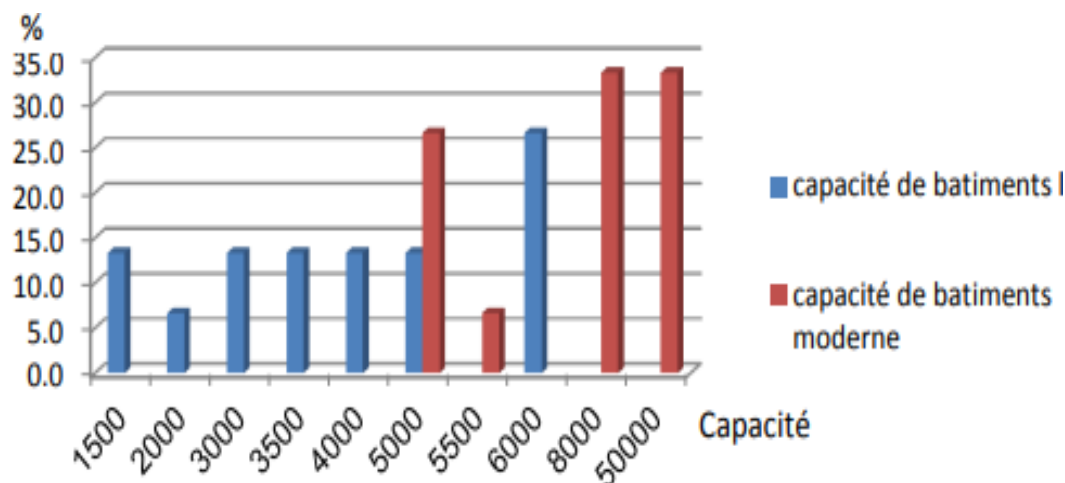


Figure II. 17: Capacity of buildings (traditional, modern).

It is observed that more than 26% of traditional poultry buildings have a capacity of 6,000 birds, while over 6% have a capacity of 2,000 birds. A majority of 13% fall within the range of 1,500 to 5,000 birds. In contrast, 33.3% of modern poultry buildings have capacities ranging from 8,000 to 50,000 birds, while more than 6.7% accommodate 5,500 birds, and others house 5,000 birds (26%). Figure II.17.

II.7.2 Chick density per :

The graph in Figure II.18 shows that the highest density recorded is more than 40 chicks/m², accounting for 60% of the observations. The second-highest density is 40 chicks/m², while the lowest density is associated with a timeframe of 40 months, with percentages of 27% and 13%, respectively.

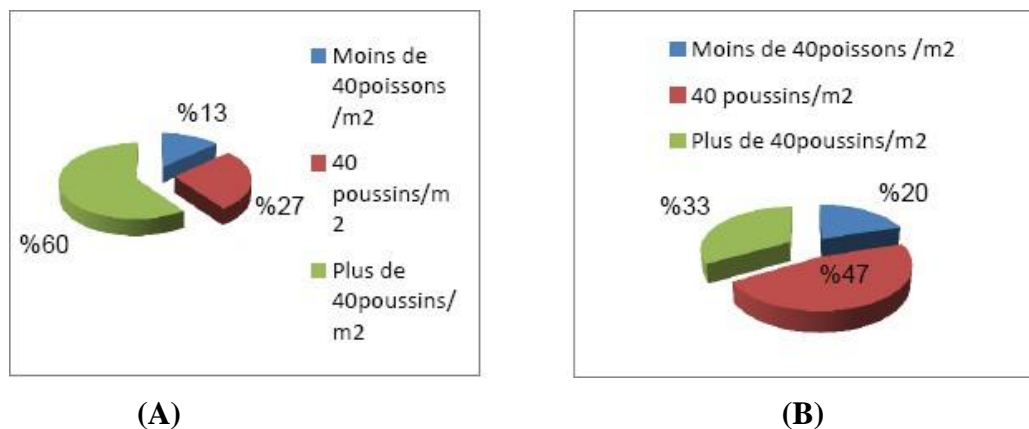


Figure II. 18 : (A): Chick density / m² traditional – (B): Chick density /m² modern.

II.7.3 Area of buildings :

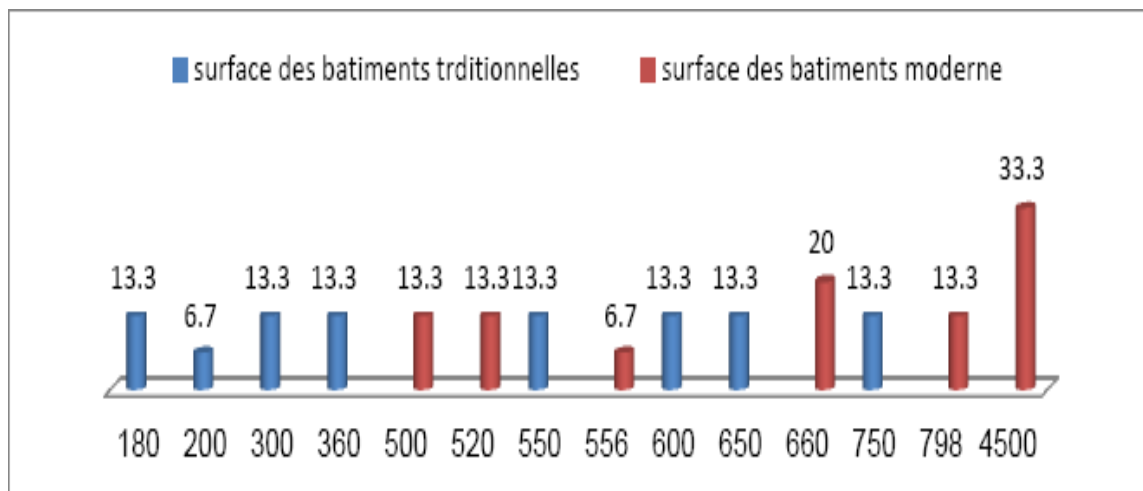


Figure II. 19 : Surface area of traditional and modern buildings.

This graph indicates that the majority of traditional buildings have surface areas ranging between 180 m² and 750 m², while more than 6% of them measure exactly 200 m². On the other hand, it is shown that 33.3% of modern buildings have a surface area of 4,500 m², while 6% of the buildings measure 556 m². Additionally, 13% to 20% of modern buildings have surface areas ranging between 500 m² and 798 m².

II.7.4 The number of chicks in buildings :

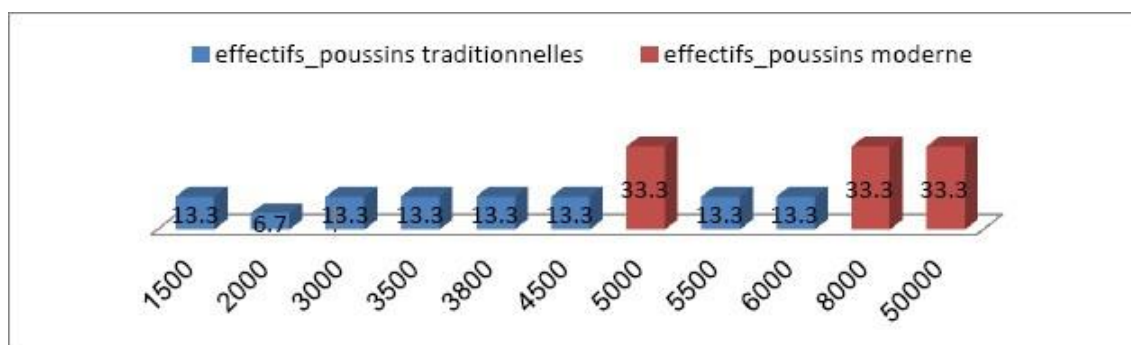


Figure II. 20: Number of chicks in buildings (traditional and modern).

The data reveals that the majority of traditional poultry houses, representing 13.3%, have a chick population ranging between 1,500 and 6,000 birds, while 6.7% of these houses house exactly 2,000 chicks. Conversely, in modern buildings, 33.3% of the structures accommodate chick populations ranging between 5,000 and 50,000 birds. (Figure II.20).

II.8 Building equipment and materials :

II.8.1 Type of drinkers :



Figure II. 21: (A) Type traditional drinkers.- (B) Type modern drinkers.

The data indicates that 87% of traditional buildings use siphoid drinkers, while 13% utilize linear nipple drinkers. (A). In contrast, 67% of modern buildings are equipped with linear nipple drinkers, and 33% use siphoid (round) drinkers. (B).

II.8.2 Type of feeders :

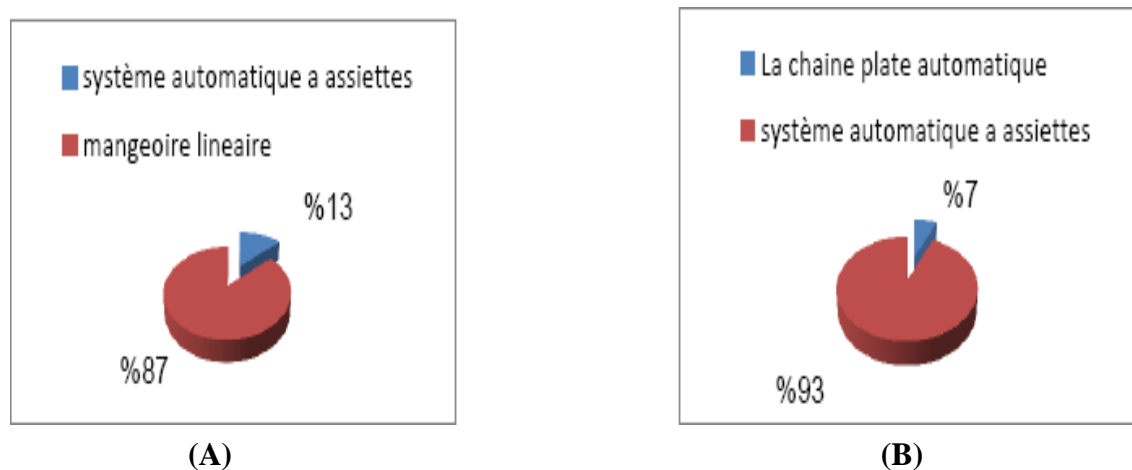


Figure II. 22 : (A) Traditional feeder type. - (B) Modern feeder type.

This graph shows that (87%) in traditional buildings used linear feeders and 13% they used automatic plate feeders. (A), on the other hand that 93% of modern buildings use automatic plate feeders. (B).

II.8.3 Type of heating :



Figure II. 23 : (A) Type of traditional heating - (B) :Type of modern heating.

The data indicates that over 80% of traditional buildings employ radiant heating, while only 13% use forced air systems. In contrast, (A) shows that 80% of modern buildings rely on forced air heating, with the remaining 20% utilizing radiant heating (B).

II.8.4 Starting temperature :

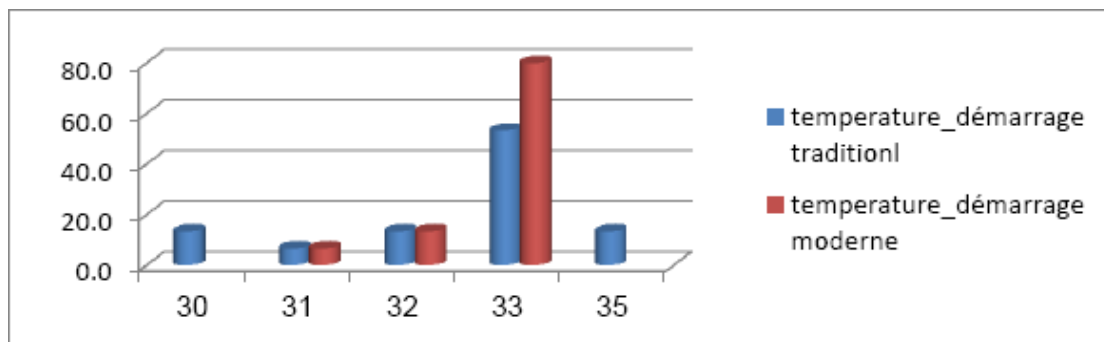


Figure II. 24 : Starting temperature of traditional and modern buildings.

The graph illustrates that 53% of traditional buildings operate at a temperature (T°) of 33°C, while more than 6% operate at T° = 31°C. Additionally, 13% of these buildings function within a temperature range of 30°C to 35°C. In contrast, the data shows that 80% of modern buildings use T° = 33°C, with a smaller proportion between 7% and 13% operating at T° = 31°C and T° = 32°C.

II.8.5 Warm-up time :



Figure II. 25 : (A) Traditional heating time. - (B) Modern heating time.

The heating time (preheating) achieved is 36 to 48 hours for 47% of the cases, whereas in traditional buildings, the preheating time is 24 hours for 53% of the cases. (A) highlights this contrast. On the other hand, (B) shows that 100% of modern buildings complete their preheating within 24 hours.

II.8.6 The period of light :

It has been observed that 100% of buildings (traditional and modern) use the light period (23h-24h).

II.8.7 Type of ventilation :



Figure II. 26 : (A) Type of traditional ventilation - (B) Type of modern ventilation

We observe that 47% of cases achieve a heating time (preheating) of 36 to 48 hours, while in traditional buildings, 53% achieve a preheating time of 24 hours. (A) illustrates this difference. On the other hand, (B) shows that 100% of modern buildings complete their preheating within 24 hours.

II.8.8 Number of mortalities in batch :



Figure II. 27: Number of deaths in batch arrivals (traditional, modern).

In this graph, it is shown that in traditional buildings, 47% experience no mortality, while between 13% and 27% have mortalities ranging from 10 to 20 subjects. However, in modern buildings, 67% show no mortality, and between 7% and 13%, there are mortalities involving 6 to 10 subjects. Figure II.27

II.8.9 Weight of each day 1 chick :

This graph indicates that in traditional breeding, 47% of the chicks on the 1st day weigh 40g, and between 13% and 25%, the weights range from 35g to 62g, respectively. However, in modern breeding, it is recorded that 33% of the chicks weigh 40g, while between 13% and 17%, the weights range from 45g to 50g. (Figure II.28)

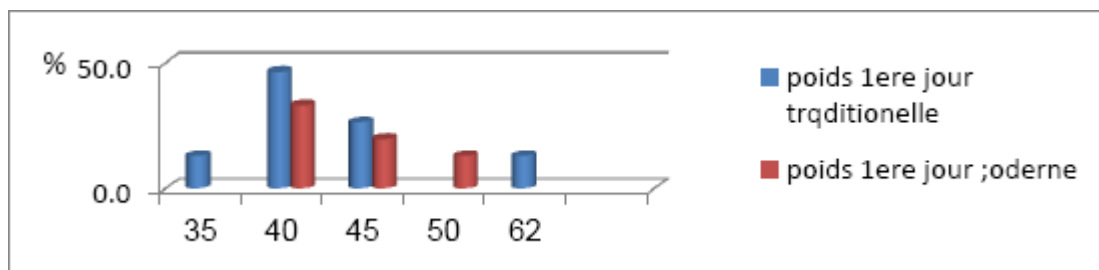


Figure II. 28: Weight of each day 1 chick (traditional, modern).

II.8.10 First week chick weight :

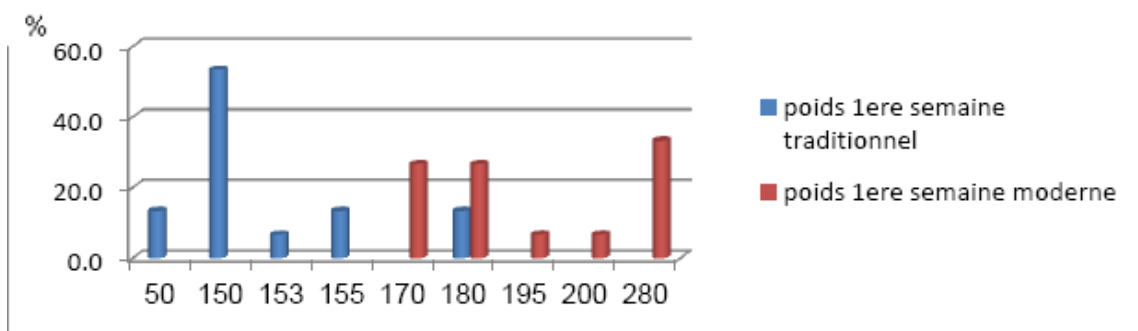


Figure II. 29: Weight of each chick in the 1st week (traditional, modern).

In traditional breeding, it is observed that the weight of the chicks during the 1st week varies from 50g to 180g. However, in modern breeding, the weights are higher, ranging from 170g to 280g. Figure II.30



Figure II. 30 : Measuring chick weight 1st week.

II.8.11 Weight of each chick of the 2nd week :

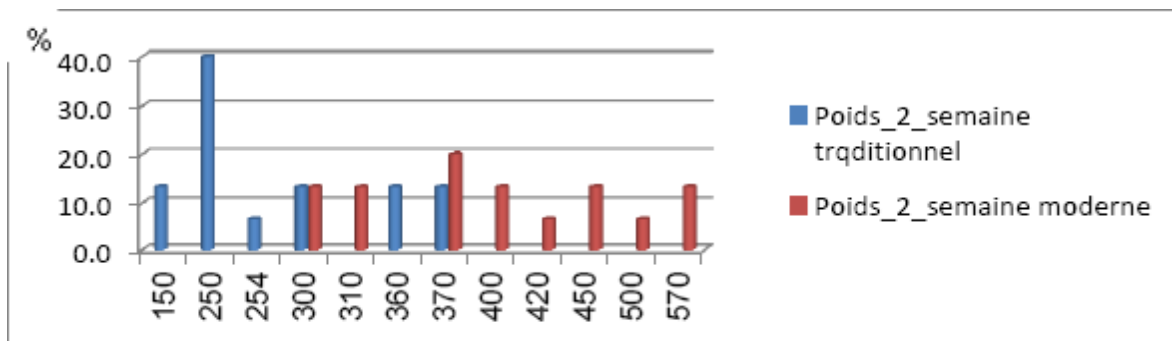


Figure II. 31 : Weight of each chick of the 2nd week (traditional, modern).

In this graph, it is shown that in traditional breeding, 40% of the chicks weigh 250g, and the same percentage of 13% of the remaining chicks have the following weights: 150g, 300g, 360g, and 370g. Additionally, 6% of the chicks weigh 254g. In modern breeding, however, 20% of the chicks weigh 370g, and the same percentage of 13% of the remaining chicks have weights ranging from 300g to 570g, while 6% of the chicks weigh between 420g and 500g. Figure II.32



Figure II. 32 : Measuring chick weight 2nd week.

II.8.12 Weight of each chick in the 3rd week :

In traditional buildings, it is recorded that only 40% of the chicks weigh 700g, and for the rest, the same percentage of 13% have weights ranging from 450g to 720g. With a low percentage, some chicks weigh 723g. However, in modern buildings, 20% of the chicks weigh 880g, while an equal percentage of 13% for the rest have weights between 800g and 945g, and 6% of the chicks weigh between 838g and 950g. Figure II.33

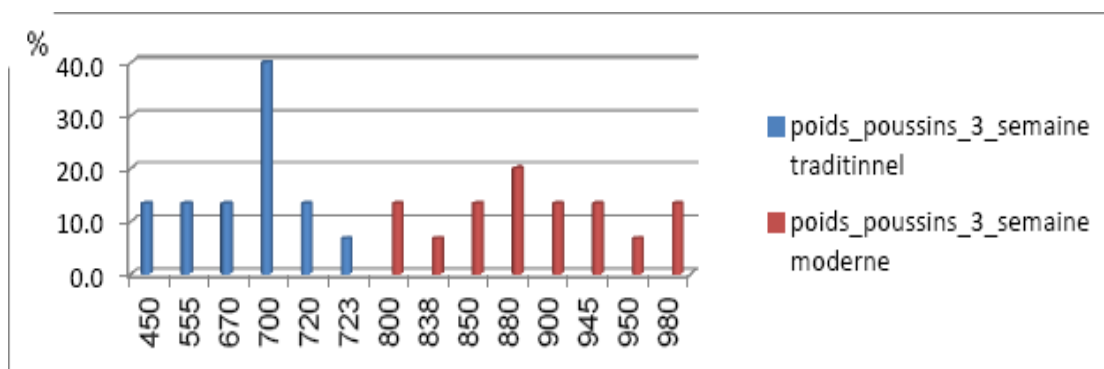


Figure II. 33 : Weight of each chick of the 2nd week (traditional, modern).

II.9 Analysis and discussion :

Based on the previous study conducted on traditional and modern poultry houses, the following conclusions can be drawn:

- Modern and advanced poultry houses produce a higher number of chickens with better quality compared to traditional poultry houses.

- The use of renewable energy sources, such as geothermal energy for heating, can significantly reduce energy consumption and contribute to environmental preservation, unlike the use of fossil fuels.

- Solar technology has the potential to achieve electrical cost savings of 30–85% in poultry farming.

- The adoption of energy-saving HVAC systems in poultry houses is not widespread in the El-Oued region due to breeders' lack of awareness about this technology.

- Ventilation technologies and wind turbines can generate approximately 2,000 kWh/year of electricity, meeting the energy needs of an entire poultry house while reducing greenhouse gas emissions by around 3.0 tons per year.

- Raising chickens using traditional methods is significantly more expensive compared to modern methods that utilize renewable and clean energy sources.

II.10 Conclusion :

In this chapter, a study, analysis, and comparison of traditional and modern poultry houses for broiler farming in the El Oued region, specifically in the municipality of El Oued El Alanda, is presented.

Through the study, it was found that poultry farmers utilizing energy-saving HVAC systems in poultry houses powered by renewable energy technologies—such as solar and geothermal energy achieve higher profits at a lower cost. These systems also result in the production of a large number of high-quality broilers due to reduced energy consumption. In contrast, traditional poultry houses, which rely on gas and fossil fuels, are not only harmful to the environment but also lead to financial losses for farmers due to the high costs of fuel, gas, and other resources.

Finally, it is evident to all that renewable and sustainable energy technologies can replace traditional HVAC systems (powered by fossil fuels, gas, etc.) in poultry houses. This shift can significantly reduce energy demand, operating expenses, and greenhouse gas emissions while increasing farmers' profitability[117].

Chapitre III :

Sizing and installation

III.1. Introduction:

Sizing involves determining the optimal dimensions and characteristics of each component in a system with a known configuration. Designing a photovoltaic system results from an iterative optimization process, as sizing is complex due to the numerous parameters involved[106].

This process follows these steps:

- Assessing the user's energy requirements
- Quantifying the available solar energy based on geographical location and environmental conditions
- Selecting photovoltaic modules
- Defining battery capacity and choosing their technology
- Sizing and selecting the charge controller
- Sizing the inverter.

III.2. Dimension of the photovoltaic installation installed at the base:

A grid-connected photovoltaic system is an installation that generates electricity using solar energy, with part or all of the produced electricity fed into the electrical grid. It primarily consists of photovoltaic modules and inverters. In the case of grid connection, the installation will include photovoltaic solar panels and inverters. Consequently, the sizing process follows a more concrete approach compared to that of an autonomous system[106].

III.2.1. Determine an energy level:

The goal is to estimate the consumption of known equipment to determine the average daily energy demand per period (summer, winter, holidays, etc.). Energy consumption is calculated as the product of power and time

$$E_i = P_i * t_i$$

Where :

E_i : Daily energy consumption of a device (Wh/day)

P_i : Power of the device (W)

t_i : Usage duration of the device (h)

This formula calculates the daily energy requirement for an application, defined as the product of power consumed and daily usage time.

The total average daily energy required E (Wh/day) is the sum of energy consumed by all system components (lighting lamps, electronic devices, etc.) :

$$E = \sum_i E_i$$

The following table provides a detailed estimation of consumption for a carpentry workshop :

Table III. 1: Energy requirements of a joinery workshop

Equipment	Number	Power (W)	Number of hours per day (h)	Energy Requirement (Kwh/day)
FAN	7	210	24	35.2
LAMP	20	16	12	3.8

III.2.2. Study of the Inclination and Orientation of the Panels:

The position of a solar panel is defined by two key parameters:

- **Orientation (azimuth)** : the angle formed with the north-south axis in the horizontal plane.
- **Tilt** : the angle formed with the horizontal plane.

• Orientation:

The sun's position varies throughout the day and seasons (east at sunrise, zenith at noon, west at sunset). Due to the Earth's axial tilt, adjust the panel orientation accordingly:

• Inclination angle :

The optimal tilt angle for solar panels is typically fixed. It is chosen to favor energy production during the least sunny month of the planned operational period. In the northern hemisphere, this corresponds to a south-facing orientation.

To determine this tilt, use the site's geographical data and consult the PVGIS (Photovoltaic Geographical Information System) website[110].

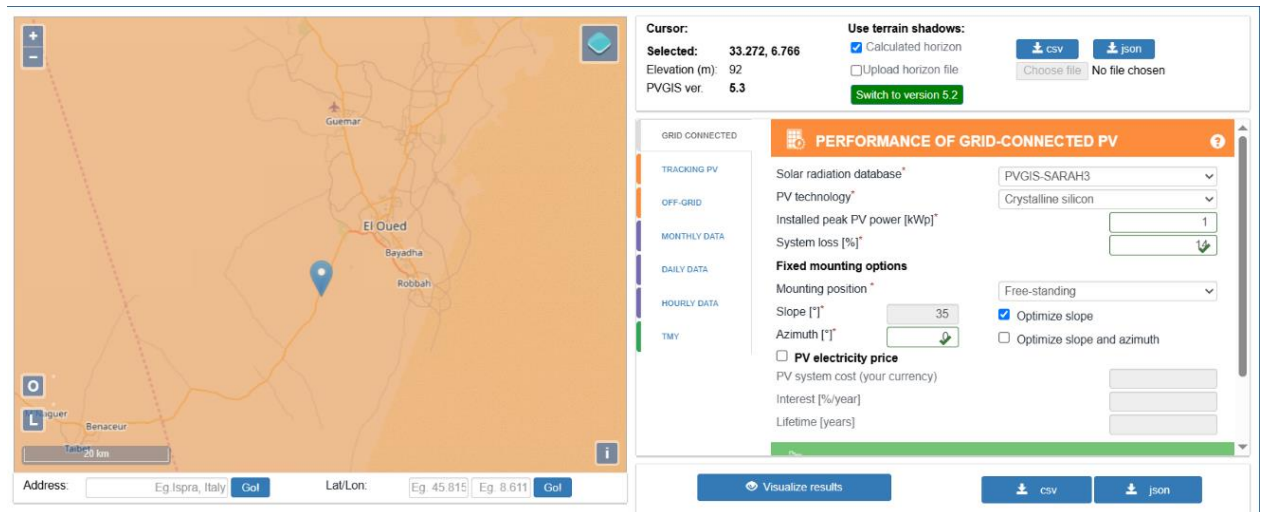


Figure III. 1: Calculation of the slope by PVGIS[110].

I click on view result and it gives me the following result:

Summary

Provided inputs:	
Location [Lat/Lon]:	33.272,6.766
Horizon:	Calculated
Database used:	PVGIS-SARAH3
PV technology:	Crystalline silicon
PV installed [kWp]:	1
System loss [%]:	14
Simulation outputs:	
Slope angle [°]:	33 (opt)
Azimuth angle [°]:	0
Yearly PV energy production [kWh]:	1877.21
Yearly in-plane irradiation [kWh/m ²]:	2450.16
Year-to-year variability [kWh]:	22.67
Changes in output due to:	
Angle of incidence [%]:	-2.5
Spectral effects [%]:	0.4
Temperature and low irradiance [%]:	-8.99
Total loss [%]:	-23.38

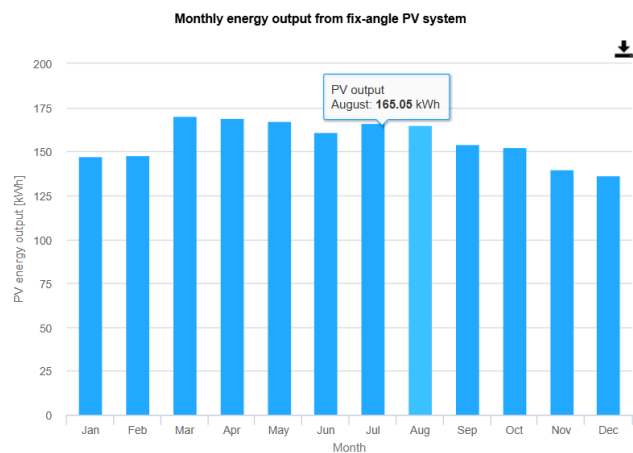


Figure III. 2: Result of tilt visualization in PVGIS.

So we orient our panel towards the south for an inclination of 33°.

III.2.3. Sizing of photovoltaic modules:

III.2.3.1. Calculation of the peak power of the system:

Photovoltaic installations are classified according to the peak power given in WC,

This power represents the maximum power that can be supplied by the power plant under standard conditions.

Standard sunshine conditions are defined by an irradiance of 1000 W.m⁻² and a temperature of temperature of 20°C.

This power is calculated so as to satisfy requirements during the most unfavourable period using the following formula:

$$P_c = \frac{E_b}{I_r * K}$$

E_b: Energy required (Wh/d).

I_r: Solar irradiation in the worst month (Kwh/m².day).

K: Correction factor taking into account the various yields , has an average value of 0.75 (without unit).

The most unfavourable month in Fez is December; the typical day in this month has a global irradiation of

$$I_r = 3.2$$

Table III. 2: Solar irradiation in El oued (source: PVGIS).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Solar irradiation (Kwh/m ² .day)	3.5	4.5	5.8	6.9	7.5	7.8	7.8	7.1	5.9	4.6	3.6	3.2

$$P_c = \frac{39}{3.2 * 0.75}$$

$$P_c = 16.25 \text{ Kwc.}$$

III.2.3.2. Photovoltaic field voltage :

The selection of a system's nominal voltage is influenced by the availability of compatible equipment (photovoltaic modules and electrical loads) as well as the required power and energy

levels, which vary depending on the specific application type (e.g., residential, industrial, or off-grid systems) [107].

The table shows the corresponding system voltages at each peak power interval.

Table III. 3: System voltages corresponding to each peak power interval.

Power peak (WC)	Less than 500WC	From 501WC to 2000WC	From 2001WC to 10000WC	More than 10000WC
Field field (V)	12	24	48	96

III.2.3.3. Determining the number of solar panels :

Using the peak power rating of the 290Wc polycrystalline panels (refer to Appendix 1), the required number of solar panels for the installation is determined by dividing the system's total power demand by the nominal power of each individual panel[108].



Figure III. 3: Polycrystalline solar panel

Table III. 4: Characteristics of polycrystalline solar panels

Parameters	Values
Peak power P_c [W]	100
Maximum supply voltage	36,4V
Maximum power current	7,96A
Open circuit voltage	44,6V
Short-circuit current	8,54A
Solar cell size	156*156mm
Dimension	1956*992*40mm
Weight	20kg
Operating temperature	-40C - 85C
Price	12,508,80DZD

We apply the following formula:

$$N_p = \frac{P_c}{P_{pv}}$$

$$N_p = \frac{16250}{290}$$

$$N_p = 56 \text{ panels}$$

III.2.3.4. Calculation of available roof area A :

$$A = 80\text{m}^2$$

Total surface area S of the PV array: Module dimensions:

Length: 1956 mm

Width: 992mm

Therefore :

$$S=1.94m^2$$

The total surface area of the PV field: $St=1.94*80$

$$St=155.2m^2$$

The total area of the PV array is greater than the available roof area, so we are using just 50% of the consumption.

So

$$Eb = \frac{39 * 50}{100}$$

$$Eb = 19.5 \text{ Kwh/d}$$

The new peak power is :

$$Pc = \frac{19.5}{3.2 * 0.75}$$

$$Pc = 8.125 \text{ Kwc}$$

The number of panels :

$$Np = \frac{8125}{290}$$

$$Np = 28 \text{ panels}$$

Total area of PV field :

$$St = 1.94 * 28$$

$$St = 54.32 \text{ m}^2$$

So the total area of the field is less than the available roof area.

III.2.3.5. Regulation system:

The control system implemented in our study is based on MPPT (Maximum Power Point Tracking) charge controllers. These regulators manage the current and voltage at the panel output. MPPT technology provides excellent performance by continuously calculating the optimal power points in real time to ensure maximum power is delivered to the batteries[109].

Furthermore, the MPPT regulator enables full utilization of the panel voltage. This type of solar controller is particularly suitable for large photovoltaic installations, as it ensures

optimal efficiency. The solar regulators used in the PV system belong to the Rosefinch series (RF384-100) and have the specifications listed in the following table:



Figure III. 4: Rosefinch MPPT regulator

Table III. 5: Characteristics of MPPT solar controllers

Parameters	Value
Maximum panel power [W]	45000
Open Circuit Voltage of Solar Panels [V]	800
Nominal System Voltage (Battery) [V]	384
Maximum Battery Charging Current [A]	100
Conversion Efficiency	99,00 %
Dimensions (H/W/D)(mm)	530x410x162 mm
Weight(Kg)	17,50Kg
Price	204,800DZD

III.2.3.6. Conversion system :

The conversion system is composed of inverters, which convert the direct current (DC) generated by the solar panels into alternating voltage and current (AC). The solar inverter used in the PV installation described below is a 40 kW solar charger inverter (model BG40KTR). Its technical specifications are presented in the following table.



Figure III. 5: Inverter 40KW solar charger

Table III. 6: Characteristics of solar inverter

Parameters	Value
Maximum panel power [KW]	44
Maximum DC voltage [V]	230 , 400
Maximum DC current [A]	64
Maximum AC power [Hz]	40
Frequency range [Hz]	47,61,05
Frequency	50, 60
Efficiency	98,9 %
Dimensions (H/L/P) [mm]	810x645x235
Weight [Kg]	53
Price	1,824,000DZD

III.2.3.7. Storage system:

The storage system is composed of lithium-ion batteries , which offer the following advantages:

- High energy density (two to five times greater than that of nickel-metal hydride batteries, for example);
- No memory effect;

- Relatively low self-discharge rate compared to other battery types.

The batteries implemented in the PV installation are lithium-based.



Figure III. 6: Lithium battery

Table III. 7: Characteristics of Lithium battery

Parameters	Value
Rated voltage(V)	4
Rated capacity(Ah)	40
Dimensions(mm)	525*230*220 par batterie
Weight(Kg)	23.5
End voltage(V)	40
Maximum protection voltage(V)	58.4
Instantaneous charging current(A)	>80
Continuous charging current(A)	>40
Charging temperature	0°C-45°C
Operating temperature	-20°C~60°C
Certification	CE ROHS MSDS UN38.3
Price	122,273,60DZD

III.2.3.8. heat pump (ghp) :

The thermal conversion system is composed of a geothermal heat pump (GHP), which transfers heat from the ground to the building during winter and extracts heat from the building to the ground during summer. The heat pump used in the HVAC installation described below. Its technical specifications are presented in the following table.



Figure III. 7: heat pump (ghp)

Table III. 8: Characteristics of heat pump (ghp)

Parameters	Value
Cooling/heating	45/50
Low/cold temperature	53/53
Supply voltage (V)	240
Current for Cooling/heating(A)	3.98/3.53
Power for Cooling/heating(KW)	0.87/0.77
Weight (Kg)	870
Price	446.610,00DZD

III.2.3.9. Cable sizing:

Cable sizing is based on two essential criteria: the permissible voltage drop in the cable and the permissible current I_z that the cable can withstand.

- **Voltage drop :**

In theory, a cable behaves as an ideal conductor with zero resistance. However, in practice, it is not ideal and is represented by a resistance, as illustrated in Figure III.05.

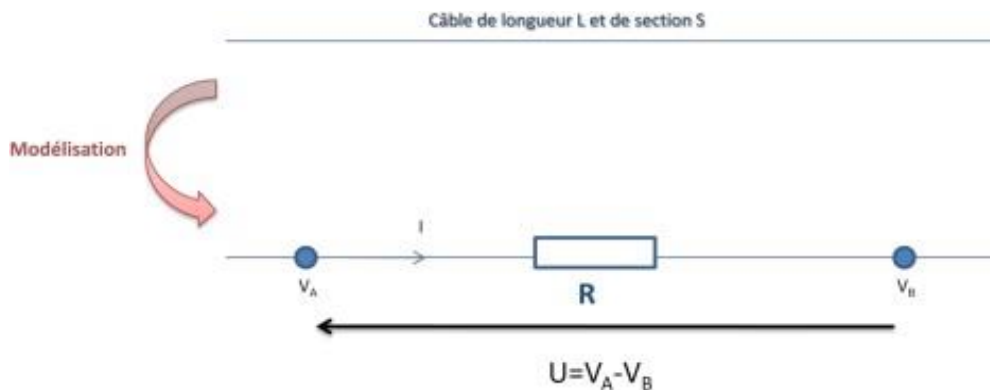


Figure III. 8: modelling a cable.

The resistance R of the cable induces a voltage drop between the two points A and B along the cable. In accordance with Ohm's law:

$$U = V_A - V_B = R * I$$

Thus, if the cable were perfectly conductive, we would have :

$$R = 0 \Rightarrow U = 0 \Rightarrow V_A = V_B$$

However, in practice, $R > 0$, which means that $V_A > V_B$; this results in a potential drop, more commonly referred to as a voltage drop. Physically, this drop reflects energy dissipation through the Joule effect, i.e., the heating of the cable. In a photovoltaic installation, such heating leads to power losses. The UTE C15-712 guide for PV systems specifies that the voltage drop should remain below 3%, with an ideal target of 1%. Formula for determining the cable cross-section:

$$N = \frac{2 * P * L * I}{S * V}$$

With:

- S : cable cross-section (mm²).
- ρ : resistivity of the conductive material (copper or aluminium) in normal service ($\rho = 0.02314 \Omega \cdot \text{mm}^2/\text{m}$)
- L : cable length (m).
- I : current flowing in the cable (A).
- ε : voltage drop ($\varepsilon = 0.03$).
- V : voltage at the origin of the cable.

A.N :

$$S = \frac{2 \cdot 0.02314 \cdot 15 \cdot 8.12}{0.03 \cdot 35.75} = 5.25 \text{ mm}^2 \approx 6 \text{ mm}^2$$

$$\varepsilon' = \frac{2 \cdot 0.02314 \cdot 15 \cdot 8.12}{6 \cdot 35.75} = 0.026$$

- **Current-carrying capacity :**

The current-carrying capacity of a cable is defined as the maximum continuous current that can flow through a conductor without causing its temperature to exceed the rated limit. Under normal operating conditions, the maximum operating current should be considered as $1.25 \times I_{CC}$. When multiple PV strings are connected in parallel, their currents must be summed [111].

Chapitre IV :

Technical and economic study

IV.1. Introduction

Following the analysis of the photovoltaic system installation, it becomes essential to evaluate the system's total annual cost. To achieve this, we calculate the discounted total cost per kilowatt-hour (kWh) delivered by the system. The cost of the kWh generated by this solar photovoltaic setup is influenced by initial fixed expenses, such as equipment purchase and installation work, and most importantly by the investment amortization period (e.g., over 10 years).

The technical and financial selection of a renewable energy option relies on understanding several key factors, including the required electrical output and the capital investment involved [113].

IV.2 Technical and economic tables for PV systems

The prices of the equipment used for the economic study were obtained from the manufacturing companies in Dragons Breath Sola

Table IV. 1: Technical and economic study of a PV system

Description	Quantity	Unit price (DZD)	Amount DZD
Polycrystalline module	28	12,508,80	350,246,4
Supports for modules	28	5,000,00	140,000,00
Cable and various	28	20,000,00	560,000,00
Regulators	1	204,800,00	204,800,00
batteries	245	122,273,60	29,957,032,00
inverter	1	1,824,000,00	1824,000.00
heat pump(ghp)	1	446.610,00	446.610,00
Total cost			33,482,688,4

The table shows that for a production of 39kW, the total cost of the photovoltaic system is: 33,482,688,4DZD.

The economic analysis used to determine the total cost of the project and the payback time is based on the following assumptions:

- Maintenance costs are assumed to be equal to 1.5% of the initial investment;

$$0.015 * 33,482,688,4 * 20 = 10,044.806.52 \text{ DZD}$$

- The cost of replacing equipment.

Assuming a lifespan of 10 years, you need to replace the batteries once during the 20-year period.

$$\text{Replacement cost} = 29,957,032 \text{ DZD}$$

This gives a total project cost 73,484,526,92 DZD

Considering the cost, Sonelgaz's kWh price per year is 400,000 DZD In 20 years is equal 8,000,000 DZD

Our user does not amortise his investment over the 20-year period, as the photovoltaic module has a lifespan of 20 to 25 years. This is not a very positive return on his investment, and we conclude that the price of the Sonelgaz kWh is cheaper than the solar kWh.

IV.3 Installation and maintenance

Installing a photovoltaic (PV) system is generally similar to setting up a conventional electrical system.

However, the use of direct current (DC) and low voltage associated with high current levels requires specific safety precautions to be observed.

Since solar panels are installed outdoors, various environmental challenges may occur, such as corrosion or material degradation, which can be influenced by salinity, the type of materials used, and installation methods.

IV.4 Mechanical and electrical installation

IV.4.1. INSTALLATION OF THE PV GENERATOR

IV.4.1.1. Masks

It is crucially important to prevent any part of the photovoltaic (PV) array from being shaded. Even a small shadow can negatively affect the system's performance in several ways:

- it may lead to damage or failure of one or more modules if the system's electrical protection is inadequate;

- it can result in a loss of energy output, depending on the extent and movement of the shadow throughout the day (and across seasons), as well as the configuration of the module strings and their series-parallel connections.

IV.4.1.2. Mounting modules in parallel rows

Occultation of a series of modules may be due to the installation of the generator itself.

The spacing between rows must take this factor into account, the most unfavourable situation being reached on the day of the winter solstice.

IV.4.1.3. Fixing the modules

Modules must be securely mounted to fulfill several key functions:

- Maintain their orientation in the face of wind, weather conditions, and potential mechanical impacts;
- Provide protection from dirt and damage originating from ground contact;
- Ensure adequate ventilation, helping to minimize heat buildup since module efficiency drops as cell temperature rises;
- Maintain the structural rigidity of the entire module assembly.

Additionally, the mounting system itself is subject to outdoor exposure and must be durable enough to last as long as the modules. Photovoltaic modules are typically enclosed in a rigid anodized aluminum frame equipped with pre-drilled mounting holes. Most systems use a standard support structure composed of a base frame that accommodates fixing nuts, which are anchored to a solid frame, such as a concrete slab.

Mounting supports are usually fabricated from anodized aluminum or stainless steel, while the fastening bolts are generally made of stainless steel for durability. The base structure that holds the modules should:

- Be capable of withstanding extreme weather, especially strong winds;
- Allow for proper air circulation behind the modules, ensuring they remain well-ventilated;

- Elevate the modules above the ground to prevent direct contact we recommend a clearance of 0.6 to 0.8 meters between the ground and the lower edge of the modules.

IV.5. Maintenance

The photovoltaic components will require maintenance and, above all, inspection to ensure that the system is working properly.

IV.5.1. Modules

The modules will be serviced each time to ensure that nothing obstructs the arrival of the radiation and that the energy produced is transmitted to the regulator. The following steps should be taken

- Clean the front of the modules with clear water approximately every 3 to 6 months to remove dirt, sand and any nests.
- Check the supports: check for corrosion and tighten the mechanical fasteners.
- Prune surrounding vegetation if it has grown
- Check connections

IV.5.2. Batteries

Maintenance operations and checks on batteries must be carried out using insulated tools and observing safety rules to avoid short circuits.

The following maintenance operations and checks will therefore be carried out:

- Measure the voltage of each cell and transfer the values to a table.
- Checking the appearance: tray normal, not deformed, terminals clean (if not, clean them).
- Maintenance of connections and cleaning of contacts.
- Visual check of electrolyte levels: add distilled water if necessary (there are two level indicators, MAX and MIN).
- Measure the specific gravity of the electrolyte in each cell.

IV.5.3. Regulators

In general, photovoltaic (PV) systems require minimal maintenance.

Routine checks should include verifying the mounting of the charge controller, ensuring the tightening of terminal connections, and confirming the sealing of cables. Under normal conditions, system parameters should remain stable over time. However, in the event of an

incidentsuch as a lightning strike near the installation it is necessary to check that the charge regulation is functioning properly and that the charging process halts as expected when the battery is full.

Based on the results obtained, the PV system under study presents both advantages and limitations, which are outlined in the following table. Notably, the photovoltaic system features a high initial investment, but very low maintenance requirements and reduced operational costs [114].

IV.6. Earthing the system

Earthing is one of the means generally recommended to avoid the destruction of part of the system by lightning.

IV.7. Conclusion

The investment cost of an autonomous hybrid system is significant, which is why the kWh produced through this system is not proportional to the price of the kWh produced by connecting to the Sonelgaz grid.

It is important to know that kilowatt-hours of solar energy are expensive. The user should choose low-consumption receivers such as the ones we recommend for lighting in our factory.

General Conclusion

General Conclusion

This study emphasizes the urgent need for sustainable and energy-efficient solutions in poultry farming, especially in arid regions like El Oued, Algeria. Traditional poultry housing systems, largely dependent on fossil fuels, are increasingly unsustainable due to their high operational costs and environmental impact. In contrast, modern systems integrating renewable energy sources—particularly hybrid solutions combining geothermal and solar technologies—offer significant benefits. These include reduced energy consumption, improved indoor environmental control, enhanced bird welfare, and greater economic profitability.

The findings clearly demonstrate that poultry farms using advanced HVAC systems powered by renewable energy achieve better productivity, lower mortality rates, and higher growth performance in broiler chickens. Moreover, the integration of energy-saving equipment and intelligent housing design (such as optimal orientation, ventilation, insulation, and cooling strategies) further contributes to environmental sustainability and operational efficiency [116].

Overall, transitioning from traditional to modern, renewable-powered poultry systems is not only a practical response to environmental and economic pressures but also a strategic necessity for the future of poultry farming. This shift will help reduce greenhouse gas emissions, lower production costs, and ensure long-term viability and food security in climate-challenged regions.

Reference

Reference

- [1] Ellabban, Omar; Abu-Rub, Haitham; Blaabjerg, Frede (2014). "Renewable energy resources: Current status, future prospects and their enabling technology". *Renewable and Sustainable Energy Reviews*. 39: 748–764 [749]. doi:10.1016/j.rser.2014.07.113
- [2] Timperly, Jocelyn (23 February 2017). "Biomass subsidies 'not fit for purpose', says Chatham House". Carbon Brief Ltd © 2020 - Company No. 07222041. Archived from the original on 6 November 2020. Retrieved 31 October 2020.
- [3] Harvey, Chelsea; Heikkinen, Niina (23 March 2018). "Congress Says Biomass Is Carbon Neutral but Scientists Disagree - Using wood as fuel source could actually increase CO2 emissions". *Scientific American*. Archived from the original on 1 November 2020. Retrieved 31 October 2020.
- [4] Suleman F, Dincer I, Agelin-Chaab M. Energy and exergy analyses of an integrated solar heat pump system. *Appl Therm Eng* 2014;73:557–64.
- [5] Casey KD, Bicudo JR, Schmidt DR, et al Air quality and emissions from livestock and poultry production/waste management systems. *ASABE*,2006, 1–40.
- [6] Defra. Heat stress in poultry: solving the problem. *J Appl Poult Res* 2005;8:18-25.
- [7] Moreki JC, 'Feeding Strategies in Poultry in Hot Climates,'*Poultry Today*,January, 1–5, 2008.
- [8] Key N, Sneeringer S, Marquardt D. Climate Change, Heat Stress, and U. S.Dairy Production. *USDA* 2014;175:1–39.
- [9] Lara LJ, Rostagno MH. Impact of heat stress on poultry production.*Animals* 2013;3:356–69.
- [10] St-Pierre NR, Cobanov B, Schnitkey G. Economic losses from heat stress by US

livestock industries. *J Dairy Sci* 2003;86:52–77.

[11] Dawkins MS, Donnelly CA, Jones TA. Chicken welfare is influenced more by housing conditions than by stocking density. *Nature* 2004;427:342–4.

[12] Abid M, Wajid HA, Khan ND, et al. Optimization of ventilation system for existing environmentally controlled poultry sheds in Pakistan. *WASJ* 2013;24:1221–33.

[13] McQuiston FC, Parker JD, Spitler JD. Heating, ventilating and air conditioning: analysis and design, 6th edn. Wiley, 2010.

[14] Ketelaars EH. Lector Notes on Chicken Farming in Warm Climate Zones. 1st ed. Wageningen: Agromisa Foundation; 2005. 128 p. ISBN: 90 5285 006.

[15] Oloyo A. The use of housing system in the management of heat stress in poultry production in hot and humid climate: A review. *Poultry Science Journal*. 2018;6(1):19

[16] Hulzebosch J. What affects the climate in poultry houses? *World Poultry*. 2004;20:36–38.

[17] Dagher NJ. Nutritional strategies to reduce heat stress in broilers and broiler breeders. *Lohmann Information*. 2008;44(1):6–15.

[18] Holik V. Management of laying hens to minimize heat stress. *Lohmann Information*. 2009;44:16–29.

[19] Bhadauria P, Kataria JM, Majumdar S, Bhanja SK, Kolluri G. Impact of hot climate on poultry production system—A review. *Journal of Poultry Science and Technology*. 2014;2:56–63.

[20] Mack LA, Felver-Gant JN, Dennis RL, Cheng HW. Genetic variation alter production and behavioral responses following heat stress in 2 strains of laying hens. *Poultry Science*. 2013;92:285–294. DOI: 10.3382/ps.2012-02589.

[21] Simmons JD, Lott BD, Miles DM. The effects of high air velocity on broiler performance. *Poultry Science*. 2003;82:232–234. DOI: 10.1093/ps/82.2.232.

- [22] Pesti GM, Armato SV, Minear LR. Water consumption of broiler chickens under commercial conditions. *Poultry Science*. 1985;64:803-808. DOI: 10.3382/ps.0640803.
- [23] May JD, Lott BD, Simmons JD. Water consumption by broilers in high cyclic temperatures: Bell versus nipple waterers. *Poultry Science*. 1997;76:944-947. DOI: 10.1093/ps/76.7.944.
- [24] Lott BD, Simmons JD, May JD. Air velocity and high temperature effects on broiler performance. *Poultry Science*. 1998;77:391-393. DOI: 10.1093/ps/77.3.391
- [25] Dai SF, Gao F, Xu XL, Zhang WH, Song SX, Zhou GH. Effects of dietary glutamine and gammaaminobutyric acid on meat colour, pH, composition, and water- holding characteristic in broilers under cyclic heat stress. *British Poultry Science*. 2012;53(4):471-481. DOI: 10.1080/00071668.2012.719148.
- [26] Ebeid TA, Suzuki T, Sugiyama T. High temperature influences eggshell quality and calbindin-D28k localization of eggshell gland and all intestinal segments of laying hens. *Poultry Science*. 2012;91:2282-2287.
- [27] Ghazi SH, Habibian M, Moeini MM, Abdolmohammadi AR. Effects of different levels of organic and inorganic chromium on growth performance and immunocompetence of broilers under heat stress. *Biological Trace Element Research*. 2012;146:309-317. DOI: 10.1007/s12011-011-9260-1.
- [28] Imik H, Ozlu H, Gumus R, Atasever MA, Urgar S, Atasever M. Effects of ascorbic acid and alpha-lipoic acid on performance and meat quality of broilers subjected to heat stress. *British Poultry Science*. 2012;53:800-808.
- [29] Zhang ZY, Jia GQ, Zuo JJ, Zhang Y, Lei J, Ren L, et al. Effects of constant and cyclic heat stress on muscle metabolism and meat quality of broiler breast fillet and thigh meat. *Poultry Science*. 2012;91:2931-2937. DOI: 10.3382/ps.2012-02255.
- [30] Qureshi AA. Open house tips for layers in hot climate zone. *World Poultry*. 2001;17:32-34.

-
- [31] Bruce J, Drysdale EM. Trans-shell transmission. In: Board RG, Fuller R, editors. *Microbiology of the Avian Egg*. London: Chapman and Hall; 1994. pp. 63-91.
- [32] Kristensen HH, Wathes CM. Ammonia and poultry welfare: A review. *World's Poultry Science Journal*. 2000;56:235-245. DOI: 10.1079/WPS20000018.
- [33] Beker A, Vanhooser SL, Swartzlander JH, Teeter RG. Atmospheric ammonia concentration effects on broiler growth and performance. *The Journal of Applied Poultry Research*. 2004;13:5-9. DOI: 10.1093/japr/13.1.5.
- [34] Miles DM, Branton SL, Lott BD. Atmospheric ammonia is detrimental to the performance of modern commercial broilers. *Poultry Science*. 2004;83:1650-1654. DOI: 10.1093/ps/83.10.1650.
- [35] Dong H, Mangino J, Mcallister TA HD. Emissions from livestock and manure management. In: Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K, editors. *IPCC Guidelines for National Greenhouse Gas Inventories—Agriculture, Forestry, and Other Land Use*. Hayama: Institute for Global Environmental Strategies (IGES); 2006. pp. 10.1-10.87.
- [36] Kweku DW, Odum B, Addae M, Koomson AD, Kwakye BD, Ewurabena AO, et al. Greenhouse effect: Greenhouse gases and their impact on global warming. *Journal of Scientific Research & Reports*. 2017;17(6):1-9. DOI: 10.9734/JSRR/2017/39630.
- [37] Czarick M, Fairchild BD. Measuring ammonia levels in poultry houses. *Poultry Housing Tips*. 2002;14(8)
- [38] Lacy MP, Czarick M. Tunnel-ventilated broiler houses: Broiler performance and operating costs. *Journal of Applied Poultry Research*. 1992;1:104-109
- [39] Olanrewaju HA, Thaxton JP, Dozier WA, Purswell J, Roush WB, Branton SL. A review of lighting programs for broiler production. *International Journal of Poultry Science*. 2006;5:301-308. DOI: 10.3923/ijps.2006.301.308
- [40] Mendes AS, Paixão SJ, Restelatto R, Morello GM, de Moura DJ, Possenti JC. Performance and preference of broiler chickens exposed to different light sources. *Journal of*

Applied Poultry Research. 2013;22:62-70. DOI: 10.3382/japr.2012-00580.

[41] Classen HL, Riddell C, Robinson FE. Effects of increasing photoperiod length on performance and health of broiler chickens. *British Poultry Science*. 1991;32:21-29. DOI: 10.1080/00071669108417324.

[42] Riddell C, Classen HL. Effects of increasing photoperiod length and anticoccidials on performance and health of roaster chickens. *Avian Diseases*. 1992;36:491-498. DOI: 10.2307/1591739.

[43] Morris MP. National survey of leg problems. *Broiler Industry*. 1993;93(5):20-24

[44] Classen HL, Annett CB, Schwean-Lardner KV, Gonda R, Derow D. The effects of lighting programmes with twelve hours of darkness per day provided in one, six or twelve hour intervals on the productivity and health of broiler chickens. *British Poultry Science*. 2004;45:S31-S32. DOI: 10.1080/00071660410001698137

[45] Petek MG, Nmez SO, Yildiz H, Baspinar H. Effects of different management factors on broiler performance and incidence of tibial dyschondroplasia. *British Poultry Science*. 2005;46:16-21

[46] Gordon SH. Effects of day length and increasing day length programs on broiler welfare and performance. *World's Poultry Science Journal*. 1994;50:269-282

[47] Davis J, Thomas PB, Siopes TD. More evidence for light-dark growing. *Broiler Industry*. 1997;2:31-32

[48] Rozenboim I, Robinson B, Rosenstrauch A. Effect of light source and regimen on growing broilers. *British Poultry Science*. 1999;40:452-457. DOI: 10.1080/00071669987197

[49] Renden JA, Bilgili SF, Lien RJ, Kincaid SA. Live performance and yields of broilers provided various lighting schedules. *Poultry Science*. 1991;70(10):2055- 2062. DOI: 10.3382/ps.0702055

[50] Leeson S, Caston LJ, Summers JD. Performance of layers given two-hour midnight lighting as growing pullets. *Journal of Applied Poultry Research*. 2003;12:313-320. DOI: 10.1093/japr/12.3.313

-
- [51] Leeson S, Caston LJ, Summers JD. Potential for midnight lighting to influence development of growing leghorn pullets. *Journal of Applied Poultry Research*. 2003;12:306-312. DOI: 10.1093/japr/12.3.306
- [52] Kritensen HH, Aerts JM, Leroy T, Berckmans D, Wathes CM. Using light to control broiler chickens. *British Poultry Science*. 2004;45:S30-S31
- [53] Lewis PD, Morris TR. Poultry and coloured light. *Worlds Poultry Science Journal*. 2002;56:189-207
- [54] Jiang J, Pan J, Wang Y, Ye Z, Ying Y. Effect of light color on growth and waste emission of broilers. In: *Proceeding 9th Int. Livest. Env. Symp., Am. Soc. Agric. Biol. Eng. (ASABE); 8-12 July 2012. Spain. New York: Curran Associates, Inc; 2013. pp. 75-80*
- [55] Kim MJ, Parvin R, Mushtaq MMH, Hwangbo J, Kim JH, Na JC, et al. Growth performance and hematological traits of broiler chickens reared under assorted monochromatic light sources. *Poultry Science*. 2012;92:1461-1466. DOI: 10.3382/ps.2012-02945
- [57] Gordon RF. *Poultry Disease*. 2nd ed. London: Baillière Tindall; 1982. p. 370
- [58] Clark JA. *Environmental Aspects of Housing for Animal Production*. 1st ed. London, Butterworths; 2013. p. 528
- [59] Saxena HC, ketelaars EH. *Poultry Production in Hot Climatic Zones*. 3rd ed. New Delhi-Ludhiana: Kalyani Publishers; 2000. 190 p
- [60] Anon. *CIBS Guide A6 Solar Data*. London: The Chartered Institution of Building Services; 1975
- [61] Timmons MB. Improving ventilation in open-type poultry housing. In: *Proceedings of the 1989 Poultry Symposium; 1989. USA; 1989. pp. 1-8*
- [62] Chepete HJ, Xin H. Heat and moisture production of poultry and their housing systems—A literature review. In: *Proceedings of the 6th International Symposium; 2001; USA. Washington, DC: ASAE; 2001. pp. 319-335*
- [63] from a website : <https://www.roysfarm.com/how-to-build-a-poultry-house/>

-
- [64] from a website : <https://www.laafon.com>
- [65] N. Alloui and O. Bennoune 614 World's Poultry Science Journal, Vol. 69, September 2013.
- [66] MARD (2005) Agriculture situation report. Direction of agricultural statistics and information systems.
- [67] MARD (2012) Le renouveau agricole et rural en marche : revue et perspective. (Bir Mourad Rais Algiers, official printing press).
- [68] Comprehensive HVAC designs (A Handbook on a practical approach to Air conditioning, Heating and Ventilation system)-N. C. Gupta
- [69] HVAC Systems Design Handbook, Fifth Edition-By by Roger Haines and Michael Myers
- [70] hybrid HVAC system www.drenergysaver.com .
- [71] from a website : <https://afs.ca.uky.edu/poultry/chapter-7-naturalventilation-systems>
- [72] Alloui, N, 2006 . 2013- Cours zootechnie aviaire, université –El hadj Lakhdar - Batna, département de vétérinaire .p p 2- 11.
- [73] from a website : <http://www.avicultureaumaroc2018.com>: Anonyme, 2018 - Aviculture au Maroc.
- [74] Hubbard, 2015- Bibliothèque technique, Guide d'élevage poulet de chair (PDF en ligne) <http://www.hubbardbreeders.com/fr/technique/bibliotheque/technique>. p11.
- [75] Aviagen, 2014- (Arbor Acres) poulet manuel d'élevage. pp 6 – 19.
- [76] Aviagen, 2014- (Arbor Acres) poulet manuel d'élevage. pp 6 – 19.
- [77] Hubbard, 2016 - Bibliothèque technique, Guide d'élevage poulet de chair (PDF en ligne). <http://www.hubbardbreeders.com/fr/technique/bibliotheque/technique>pp17 - 38.
- [78] Cobb , Europe Ltd , 2011 -le guide d'élevage poulets de chair (cobb-vantress.com) p p7 -21.
- [79] Surdeau Et Henaff, 1979- La Production Du Poulet. Ed J.- B.BAILLIERE, Paris .Pp16 – 18.

-
- [80] World Meteorological Organization. Global Climate in 2015–2019: Climate Change Accelerates. <https://public.wmo.int/en/media/press-release/global-climate-2015-2019-climate-change-accelerates> (September 2019, date last accessed)
- [81] Wang Y, Sun X, Wang B, Liu X. Energy saving, GHG abatement and industrial growth in OECD countries: a green productivity approach. *Energy* 2020;194:116833.
- [82] Ang CP, Toper B, Gambhir A. Financial impacts of UK's energy and climate change policies on commercial and industrial businesses. *Energy Policy* 2016;91:273–86.
- [83] Sneessens I, Sauvée L, Randrianasolo-Rakotobe H, Ingrand S. A framework to assess the economic vulnerability of farming systems: application to mixed crop-livestock systems. *Agric Syst* 2019;176:102658.
- [84] Purdy A, Pathare PB, Wang Y et al. Towards sustainable farming: feasibility study into energy recovery from bio-waste on a small-scale dairy farm. *J Clean Prod* 2018;174:899–904.
- [85] Mile DM, Logan JW, Arora S, Jenkins JN. On-farm resources and renewable energy in broiler chicken production: Brinson farms case study. *Int J Poultry Sci* 2016;15:41–7.
- [86] Guler T, Elmer T, Cui Y et al. Experimental investigation of a novel PVt/heat pump system for energy-efficient poultry houses. *Int J Low Carbon Technol* 2018;13:404–13.
- [87] Kapica J, Pawlak H, Scibisz M. Carbon dioxide emission reduction by heating poultry houses from renewable energy sources in Central Europe. *Agric Syst* 2015;139:238–49.
- [88] Trypanagnostopoulos G, Kavga A, Souliotis M, Tripanagnostopoulos Y. Greenhouse performance results for roof installed photovoltaics. Performance results for roof installed photovoltaics. *Renewable Energy* 2017;111:724–31.
- [89] Mobtaker HG, Ajabshirchi Y, Ranjbar SF, Matloobi M. Solar energy conservation in greenhouse: thermal analysis and experimental validation. *Renew Energy*

2016;96:509–19.

[90] Joudi KA, Farhan AA. Greenhouse heating by solar air heaters on the roof. *Renew Energy* 2014;72:406–14.

[91] Cossu M, Murgia L, Ledda L et al. Solar radiation distribution inside a greenhouse with south-oriented photovoltaic roofs and effects on crop productivity. *Appl Energy* 2014;133:89–100.

[92] Islam M, Mun HS, Bostamia ABMR et al. Evaluation of a ground source geothermal heat pump to save energy and reduce CO₂ and noxious gas emissions in a pig house. *Energy Build* 2016;111:446–54.

[93] Li H, Rong L, Zhang G. Numerical study on the convective heat transfer of fattening pig in groups in a mechanical ventilated pig house. *Comput Electron Agric* 2018;149:90–100.

[94] Tamvakidis S, Firfiris VK, Martzopoulou A et al. Performance evaluation of a hybrid solar heating system for farrowing houses. *Energy Build* 2015;97:162–74.

[95] Wiedemann SG, McGahan EG, Murphy CM. Resource use and environmental impacts from Australian chicken meat production. *J Cleaner Prod* 2017;140:675–84.

[96] Pereira JLS. Assessment of ammonia and greenhouse gas emissions from broiler houses in Portugal. *Atmos Pollut Res* 2017;8:949–55.

[97] Cui Y, Elmer T, Guler T et al. A comprehensive review on renewable and sustainable heating systems for poultry farming. *Low Carbon Technol* 2020;15:121–42.

[98] Tańczuk M, Junga R, Werle S et al. Experimental analysis of the fixed bed gasification process of the mixtures of the chicken manure with biomass. *Renew Energy* 2019;136:1055–63.

[99] Dalólio FS, Silva JND, Oliveira ACC, Tinôco IFF. Poultry litter as biomass energy: a review and future perspectives. *Renew Sust Energ Rev* 2017;76:941–9.

[100] Mirzaee-Ghaleh E, Omid M, Keyhani A, Javadikia P. Forecasting the thermal load

for implementing solar energy in a model poultry house. J Agric Eng Biotechnol 2013;1:30–6.

[101] Chen W, Sheng C. Mitigation of carbon dioxide emissions in a warming system for chicks by using solar energy. Life Sci J 2013;10:1845–50.

[102] Fawaza H, Abiad MG, Ghaddar N, Ghali K. Solar-assisted localized ventilation system for poultry brooding. Energy Build 2014;71:142–54.

[103] Kapica J, Pawlak H, Scibisz M. Carbon dioxide emission reduction by heating poultry houses from renewable energy sources in Centre Europe. Agric Syst 2015;139:238–49.

[104] Choi HC, Salim HM, Akter N et al. Effect of heating system using a geothermal heat pump on the production performance and housing environment of broiler chickens. Poultry Sci 2012;91:275–81.

[105] Kharseh M, Nordell B. Sustainable heating and cooling systems for agriculture. Int J Energy Res 2014;35:415–22.

[106] Choi HC, Salim HM, Akter N, Na JC, Kang HK, Kim MJ. Effect of heating system using a geothermal heat pump on the production performance and housing environment of broiler chickens. Poultry Science. 2012; 91: 275-228.

[107] : Antonio Luque and Steven «Hegedus, *Handbook of Photovoltaic Science and Engineering*», John Wiley & Sons Ltd, 2003

[108] :N. Abouchabana, « *Etude d'une nouvelle topologie buck-boost appliquée à un MPPT* »,

[109] Mémoire de Magistère, Ecole Nationale Polytechnique, Alger, Algérie, 2009.

[110] : S. Sumathi, « *Solar PV and wind Energy conversion systems* », Springer, Switzerland 2015.

[111] from a website : <https://ec.europa.eu/jrc/en/pvgis>.

-
- [112] from a website : http://www.elysun.fr/pdf/elysun_290w_poly.pdf.
- [113] from a website : <https://ar.ensolar.com/pv/inverter-datasheet/10502>
- [114] H. Yotto « Etude et conception d'une mini centrale PV » mémoire fin d'études Master 2 IE Bénin 2011.
- [115] M. Nkouimi « outil d'aide au dimensionnement des système photovoltaïques domestiques » mémoire de fin d'étude pour l'obtention du diplôme d'ingénieur de conception, Ecole national superieur polytechnique de Yaoundé 2010.
- [116] Rahmouni, S., Yasmina, M., Ghedamsi, R., & Settou, N. (2024). Reducing energy consumption in a poultry farm by designing and optimizing the solar heating/photovoltaic system. *Renewable Energy and Environmental Sustainability*
- [117] Aidat, T., Benziouche, S. E., Cei, L., Giampietri, E., & Berti, A. (2023). Agricultural policies and the development of sustainable greenhouses in Algeria: The case of Biskra. *Sustainability*, 15(19)
- [118] Attia, Y. A., Aldhalmi, A. K., Youssef, I. M., Al-Harhi, M. A., Abd El-Hack, M. E., & Azzam, M. M. M. (2024). Challenges to poultry industry due to climate change: Heat stress implications and solutions. *Discover Sustainability*, 5(1), 11.
- [119] Benkhaled, M., Benmessaoud, M. T., & Boudghene Stambouli, A. (2023). Integration of solar energy into the Algerian electricity system. *Buildings*, 15(6),
- [120] Chabane, F., Laouer, A., & Moummi, N. (2024). Evaluation of thermal and energy performance in educational buildings in Mediterranean climate: The case of Ain Temouchent, Algeria. In *Proceedings of the International Conference on Green Energy and Environmental Engineering* (pp. xxx–xxx). Springer.