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بسم الله الرحمن الرحيم

ال حمد لله الذي بنعمته تتم الصالحات، وأشكره على توفيقه وهدايته في كل خطوة خطوتها في هذا العمل

Dedicace

To my dear father,
who made countless sacrifices for my education and success, I offer this as an expression of my profound gratitude.
To my beloved mother,
who has endured years of hardships, I gift you this humble act as a token of my deep affection and sincere love.
To my dear brothers and sisters,
who have accompanied me through life's journey with all its challenges, thank you for your unwavering support.
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I dedicate this modest work:

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In memory of my father,

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To my wife,

for her understanding and wisdom.

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who accompanied me through the trials of life.

For their help and realization of this work.

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in memory of my grandparents.

To all my friends and comrades.

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HAMMIA Ahmed Saber.

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I dedicate this modest work:
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To my wife,
To my children,
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Abstract

This thesis explores an experimental study on a prototype solar thermal collector designed for heating a poultry house in the arid regions of Algeria, particularly in El Oued. This model is constructed with insulating walls, using sandwich panels. The heating device consists of a wooden structure installed above the poultry house, equipped with a first layer of iron plates painted black to maximize the absorption of solar rays, and a second layer made of glass plates that act as a flat solar collector. This setup allows air to enter from one side, circulate under the iron plates, and then escape through ducts on the opposite side.

An airflow is introduced under the solar collector, drawing warm air into the poultry house, complemented by a special fan that extracts air from the inside to the outside. Measurements taken between 9:30 AM and 2:00 PM showed that increasing the number of ducts delivering hot air into the poultry house and the use of multiple fans raise the internal temperature.

The results demonstrate that this thermal system is effective in heating and distributing air inside the poultry house, thereby helping to create a conducive environment using solar energy, which can enhance production and reduce energy costs.

Keywords: thermal collector, poultry, heating, energy efficiency.

Résumé

Ce mémoire explore une étude expérimentale sur un prototype de collecteur solaire thermique destiné au chauffage d'un poulailler dans les régions arides d'Algérie, notamment à El Oued. Ce modèle est conçu avec des murs isolants, utilisant des panneaux sandwichs. Le dispositif de chauffage comprend une structure en bois installée au-dessus du poulailler, équipée d'une première couche de plaques de fer peintes en noir pour maximiser l'absorption des rayons solaires, et d'une seconde couche composée de plaques de verre qui fonctionnent comme un collecteur solaire plat. Cette configuration permet à l'air de pénétrer d'un seul côté, de circuler sous les plaques de fer, puis de s'échapper par des conduits situés du côté opposé.

Un écoulement d'air est introduit sous le collecteur solaire, aspirant l'air chaud vers l'intérieur du poulailler, complété par un ventilateur spécial qui extrait l'air de l'intérieur vers l'extérieur. Des mesures réalisées entre 9h30 et 14h00 ont montré que l'augmentation du nombre de conduits acheminant l'air chaud dans le poulailler et l'utilisation de plusieurs ventilateurs élèvent la température interne.

Les résultats démontrent que ce système thermique est efficace pour chauffer et répartir l'air à l'intérieur du poulailler, contribuant ainsi à créer un environnement propice utilisant l'énergie solaire, ce qui peut améliorer la production et diminuer les dépenses énergétiques.

Mots-clés : collecteur thermique, poulaille, chauffage, efficacité énergétique.

ملخص

هذه المذكرة تتناول الدراسة التجريبية لنموذج أولي لمجمع طاقة الحرارية من الشمس المستخدم لتدفئة حظيرة تربية الدواجن الموجودة في المناطق القاحلة في الجزائر (الوادي). لقد صميم هذا النموذج بجدران عازلة مثل الألواح الشطيرة. نظام التدفئة يتكون من هيكل خشبي مثبت فوق الحظيرة مكون من طبقة اولى من الالوح الحديدية مطلية باللون الأسود لامتصاص أشعة الشمس, والطبقة الثانية من الالواح الزجاجة عبارة عن لاقط شمسي مسطح. هذا الهيكل يسمح بدخول الهواء فقط من جانب واحد ويمر أسفل الألواح الحديدية ويخرج من الانابيب الموجودة بالجانب المعاكس. يوجد تيار هوائي يدخل يمر تحت اللاقط الشمسي يسحب الهواء الساخن الى داخل الحظيرة بالإضافة إلى مروحة خاصة تسحب الهواء من داخل الحظيرة الى خارجها. لقد قمنا بسلسلة من القياسات التي تم إجراؤها من الساعة 9:30 صباحا حتى الساعة 2:00 زولا، لاحظنا أن بزايدة عدد الانابيب التي توصل الهواء الساخن الى الحظيرة وكذألك استعمال أكثر من مروحة يرفع من درجة الحرارة داخل الحظيرة.

تشير النتائج المتحصل عليها إلى أن هذا النظام الحراري يعمل بفعالية جيدة في تسخين الهواء وتوزيعه داخل الحظيرة، وهذا قد يساهم في توفير بيئة دافئة لحظيرة الدجاج باستخدام الطاقة الشمسية مع زيادة وتحسين الإنتاج وتقليل تكاليف الطاقة.

الكلمات المفتاحية: مجمع حراري، حضيرة الدواجن، التدفئة، الكفاءة الطاقوية.

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General conclusion

GENERAL INTRODUCTION:

Because poultry are sensitive to temperature fluctuations, maintaining the correct temperature inside the house is crucial to ensuring their health and productivity.

Basic equipment for a winter poultry house includes a heater. Heating systems play an important role in providing the optimal temperature required for poultry growth and comfort. These systems rely on a variety of technologies, including electric heating, gas heating and central heating. Each of these systems has its own advantages and disadvantages, and the appropriate system must be selected based on factors such as the size of the poultry house, cost, and energy efficiency.

Electric heaters are a common choice for poultry houses because of their ease of installation and use and their ability to provide instant heat. Although gas heaters are an economical option in terms of running costs, they require good ventilation to avoid the build-up of harmful gases. Central heating systems, on the other hand, offer integrated solutions for temperature and humidity control in large poultry houses.

In this study, we focus on evaluating the effectiveness and efficiency of different heating systems used in winter poultry houses. We analysed several heating systems for their ability to provide adequate heat, energy efficiency and environmental impact. We also conducted practical experiments measuring the temperature and energy consumption of poultry houses to identify the best solutions to ensure an ideal poultry environment at the lowest possible cost.

The research content mainly includes three chapters:

The first chapter presents the theoretical background of poultry house heating technology and reviews the literature on this subject. This review includes previous studies on the importance of providing a suitable thermal environment for poultry, and the impact of temperatures on poultry health and productivity. The chapter also addresses technical developments in different heating systems, and reviews research on the efficiency of these systems to achieve optimal heating efficiently and safely. The chapter also includes a discussion on common challenges and problems faced by previous research, proposed solutions to improve performance and reduce energy consumption.

Second chapter provides an overview of the latest heating systems used in poultry houses, detailing experimental methods. The chapter addresses the latest technologies available, such as infrared heating systems, smart fireplaces, and hybrid heating systems that combine traditional and renewable sources of energy. How each system works, the advantages and disadvantages associated with it are explained. The chapter also describes the experimental methods used to assess the performance of these systems, including thermal measurements and energy consumption analysis, to ensure that the ideal environment for poultry is provided at the lowest possible cost.

Third chapter presents the results of the experiment and discussion, with a focus on identifying optimal heating systems based on specific criteria, including energy efficiency, cost and environmental impact. Data generated by experiments are analysed, and the performance of different systems is compared based on the said criteria. The chapter also addresses recommendations for improving existing heating systems, suggestions for developing new technologies that contribute to increasing efficiency and reducing operational costs and negative environmental impacts. In the end, the chapter provides a comprehensive compendium that includes the best solutions for heating poultry houses in winter based on the results of the study.

In summary, from this study we derived best practices for using efficient and sustainable heating systems in poultry houses and provided recommendations to improve performance and reduce environmental impact.

Chapter I
Bibliographic studies

I.1. Introduction:

Poultry is considered an important economic source and a primary source of animal protein, particularly in developing countries. Hence, the rapid growth of this industry over the past few years worldwide can be explained.

This statistical study aims to track the development of the number of researches focusing on the conditions of poultry shelters, their heating, and the search for solutions to moisture problems inside them. Researchers aim to review the extent of interest in such studies at both the national and international levels.

FigI-1 : Old poultry farms.

FigI-2: Modern poultry farms.

The structure serves as a refuge for animals, shielding them from disturbances and providing optimal comfort conditions. It's crucial to factor in both internal and external elements when planning a building, especially when establishing a broiler chicken farm. Success hinges on creating an environment conducive to their well-being, including suitable habitat, proper nutrition, sufficient hydration, and effective health safeguards through a bioengineering strategy.

The investigation into the impact of climatic variables, particularly temperature and humidity, on poultry housing has captured considerable attention from scientists over the years. Before delving into the theoretical aspect, it is crucial to offer a concise summary of this research.

I.2.Brief history of heating devices:

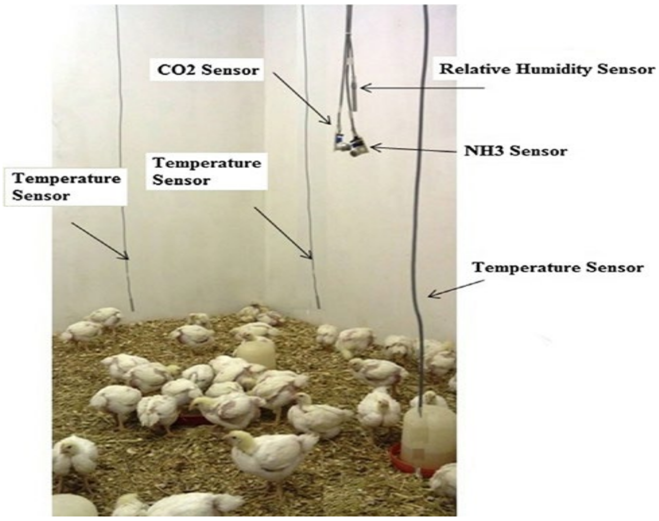
In 2007, the American Society of Agricultural and Biological Engineers released a publication in St. Joseph highlighting that fuel consumption represents a significant portion of the energy expenses associated with agricultural operations during winter poultry rearing seasons. The escalating costs of fuel have underscored the necessity for alternative approaches to curtail energy consumption in broiler production. This study aimed to assess the viability of utilizing the attic space within a broiler house as a source of pre-heated air to diminish energy usage during winter flocks. A set of air inlets was installed in the ceiling of a broiler house to deliver pre-heated air during the brooding phase. These inlets were positioned at the peak of the ceiling and operated manually using a curtain actuator. Temperature and relative humidity data were gathered for the brood chamber, attic space, and outdoor environment. Additionally, the run times of the heater, brooder, and fan were monitored. The implementation of the attic inlet system resulted in a reduction in heating system run time, with an estimated saving of 128.8 liters of LP gas during the initial two weeks of a spring flock. Moreover, humidity levels decreased in the house equipped with the system; the humidity ratio with the system installed was measured at 0.0141 kg water/kg dry air compared to 0.0155 kg water/kg dry air in a house utilizing a traditional sidewall inlet system [1].

On December 14, 2011, Ehab Mostafa, In-Bok Lee, Sang-Hyeon Song, Kyeong-Seok Kwon, Il-Hwan Seo, Se-Woon Hong, Hyun-Seob Hwang, Jessie Pascual Bitog, and Hwa-Taek Han conducted a study aimed at developing ventilation systems to mitigate cold air drafts during the winter season and establish an optimal environment within broiler rearing facilities. During cold weather conditions, ventilation ducts and low airflow rates are typically utilized to maintain the required air temperature. Perforated ducts are favored for heating purposes due to their efficient and uniform distribution of air throughout the designated space.Four ventilation systems were designed to create a comfortable zone for broilers during the winter season. Computational fluid dynamics (CFD) simulations were employed to investigate these systems under realistic conditions, and field experiments were carried out to validate the designed configurations. The validation results demonstrated minimal discrepancies. The enhanced designs were evaluated against a standard design in terms of ventilation rate, air temperature distribution, and reduction in indoor gas concentration.Among the improved designs, Case Four (C-4) exhibited the highest ventilation rate within the broiler zone. In C-4, the inlet duct was positioned on one side of the building, while the outlet duct was placed on the opposite side. It achieved approximately 54% of the ventilation compared to the standard design. Additionally, all enhanced designs displayed high uniformity, ranging around 60–70% when compared to the standard design. In terms of gas dilution within the broiler zone, C-4 demonstrated a 15% reduction in ammonia concentration just three minutes after the ventilator was activated [2].

On February 17, 2013, Flávio Alves Damasceno, Jairo Alexander Osorio Saraz, Luciano Barreto Mendes, Samuel Martin, and Marcio Arêdes Martins described their study aimed at adapting and validating a computer model utilizing Computational Fluid Dynamics (CFD) for predicting temperature and air speed within a duct distribution system linked to a heating furnace commonly found in poultry houses in tropical and subtropical regions. The objective was to ensure the accuracy of the model in such environments. The validation process involved comparing the model's predictions with experimental data, yielding satisfactory results with normalized mean square error (NMSE) values of 0.25 for air temperature and 0.02 for air speed. These findings demonstrate the model's capability to accurately predict air speed and temperature within this specific system. Moreover, the study suggests that this model could be instrumental in enhancing the efficiency of heat distribution within and around air ducts by considering different air speeds, materials, and dimensions [3].

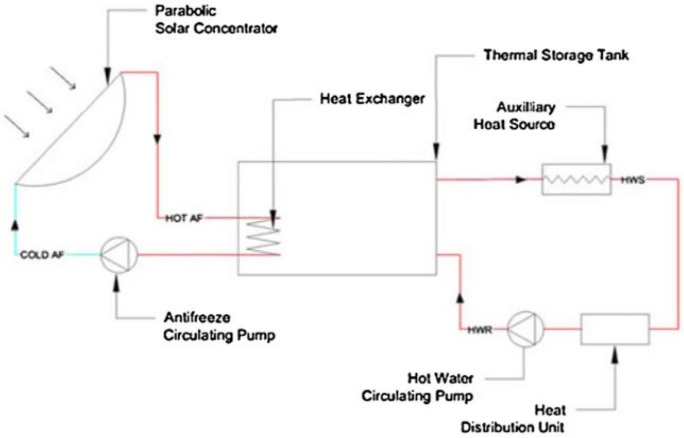
On March 30, 2013, Omar El Mogharbel, Kamel Ghali, Nesreen Ghaddar, and Mohamad G. Abiad conducted an evaluation of the performance of an innovative solar-assisted domestic pen heating system for incubation, utilizing a three-dimensional computational simulation model of the heated space.The warm air-curtained pen was designed to maintain optimal temperature, air velocity, relative humidity, and air quality, meeting the ventilation and heat requirements for a typical pen accommodating 100 chicks, as recommended by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) and the American Society of Agricultural and Biological Engineers (ASABE).The study focused on determining the supply flow characteristics and simulating the velocity and temperature field of the curtained region to ensure compliance with ventilation requirements and comfort criteria. Results indicated that air supplied at 40°C effectively created the desired microenvironment at bird level, with a heat input to the unit of 685 W when the outdoor temperature was −5°C. Furthermore, the energy performance of the system was analyzed using a prototype consisting of 16 pens. The new heating scheme exhibited significantly lower energy consumption compared to conventional non-localized systems, consuming only one third of the energy. Additionally, integration with a solar system utilizing parabolic concentrators allowed for 72% of the power load to be supplied from solar energy during winter flock operations and 100% during other seasons [4].

On June 24, 2013, E. Mirzaee-Ghaleh, M. Omid, A. Keyhani, and M.J. Dalvand conducted a study to monitor indoor climate management and compare fuzzy logic controllers with on/off controllers in a typical poultry farm in Iran.Three fuzzy controllers were developed and tested using LabVIEW software to regulate indoor parameters such as temperature, humidity, CO2, and NH3 levels to desired values. The results revealed that the fuzzy controller exhibited superior performance in regulating temperature and humidity. The fuzzy controller-maintained temperature and relative humidity within ±1°C and ±5% of set points for 78.76% and 96.83% of the working time, respectively. In contrast, the on/off controller achieved these criteria for only 31.36% and 68.35% of the time. Furthermore, the mean CO2 concentration was lower with the on/off controller (1124.64 ppm) compared to the fuzzy controller (2582 ppm), while NH3 concentration remained consistent for both controllers. The study also found that the primary energy consumption was attributed to heating the poultry house. The total power consumption by the actuators for the fuzzy system averaged 389.59 kJ/h, which was 42% lower than that of the on/off controller (664.49 kJ/h) [5].



FigI-3: Model poultry house use for experiments.

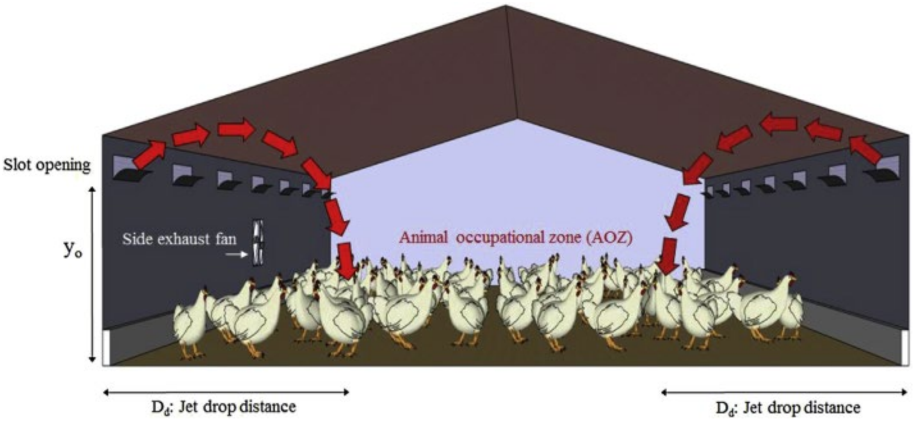
On August 23, 2013, Hajar Fawaz, Mohamad G. Abiad, Nesreen Ghaddar, and Kamel Ghali conducted a study to assess the efficiency and effectiveness of a locally powered solar heating and ventilation system for poultry incubation within a model of poultry houses comprising 16 barns.The study utilized numerical 3-D simulations to model the heated space, incorporating a convective unit to fulfill both heating and fresh air requirements while maintaining Ammonia (NH3) and Carbon Dioxide (CO2) concentrations in the chicken's microenvironment below 25 ppm and 2500 ppm, respectively, as per established standards.Results indicated that the localized system achieved significant energy savings, reducing energy demand by 74% compared to a conventional fuel-based fully mixed heating and ventilation system. Furthermore, a solar system employing parabolic concentrators covered 84% of the load required for a six-week winter flock, further emphasizing the system's effectiveness and potential for sustainable energy usage in poultry incubation operations [6].



FigI-4: Solar-assisted heating system.

In 2015, Mohamed GHONAME and Tarek FOUDA outlined the primary objectives of their study, aiming to create a thermal comfort environment, decrease energy consumption for heating purposes, and enhance meat production efficiency. The performance of the air heating system was assessed both with and without ducts throughout the 1 to 5-week life cycle of the poultry. The findings revealed that during the initial brooding stage, utilizing a forced-air heating system without a perforated polyethylene tube resulted in air temperatures near the floor being lower than the recommended levels by 4.11°C and 4.64°C at 2 and 8 days of age, respectively. Conversely, when employing the system with a perforated polyethylene tube, the air temperature near the floor was higher than recommended by 0.12°C at 3 days of age and lower by 3.36°C at 8 days of age. Additionally, the average indoor air relative humidity throughout the birds' life cycle was reduced by 12.92% when using the heater with a perforated polyethylene tube compared to without it. Furthermore, the utilization of the perforated polyethylene tube led to reductions in total energy requirements and specific heating power by 17.84% and 20.82%, respectively, by the end of the birds' life cycle, while also increasing the average body weight from 1.9 to 2.1 kg at the fifth week of age. Consequently, the study recommended operating the forced-air heating system with a perforated polyethylene tube to achieve a thermal comfort environment, decrease energy demands for heating, reduce specific heating power, and optimize meat production [7].

On January 19, 2015, Kyeong-seok Kwon, In-bok Lee, and G. Qiang Zhang emphasized the significance of controlling airflow paths through inlet openings to ensure efficient heat exchange in poultry houses, particularly during winter. They referenced a model proposed by Zhang and Strohm in 1999 to manage the cold jet path by reducing jet distance. However, this model had limitations due to its small-scale nature, limited number of slot openings, and challenges in measuring invisible airflows. To address these limitations, computational fluid dynamics (CFD) was employed to qualitatively and quantitatively analyse jet drop distances in a commercial broiler house with multiple slot openings. The study utilized regression models incorporating jet drop factor and corrected Archimedes number variables based on experimental data. CFD predictions of jet drop distances were compared with the regression models to validate the accuracy of the developed method. The results indicated that the regression model using the corrected Archimedes number more accurately predicted jet drop distances in the simulation model, achieving an R^2 value of 0.90. Subsequently, the validated method was applied to analysed jet drop distances in a mechanically ventilated broiler house with multiple slot openings. The study analysed trends of CFD-computed jet drop distances based on variables such as ventilation rate, initial angle of slot openings, and outdoor air temperature. This comprehensive approach provided valuable insights into optimizing airflow management in poultry houses to enhance thermal comfort and energy efficiency [8].



FigI-5: Concept of the jet-drop-distance in a broiler house.

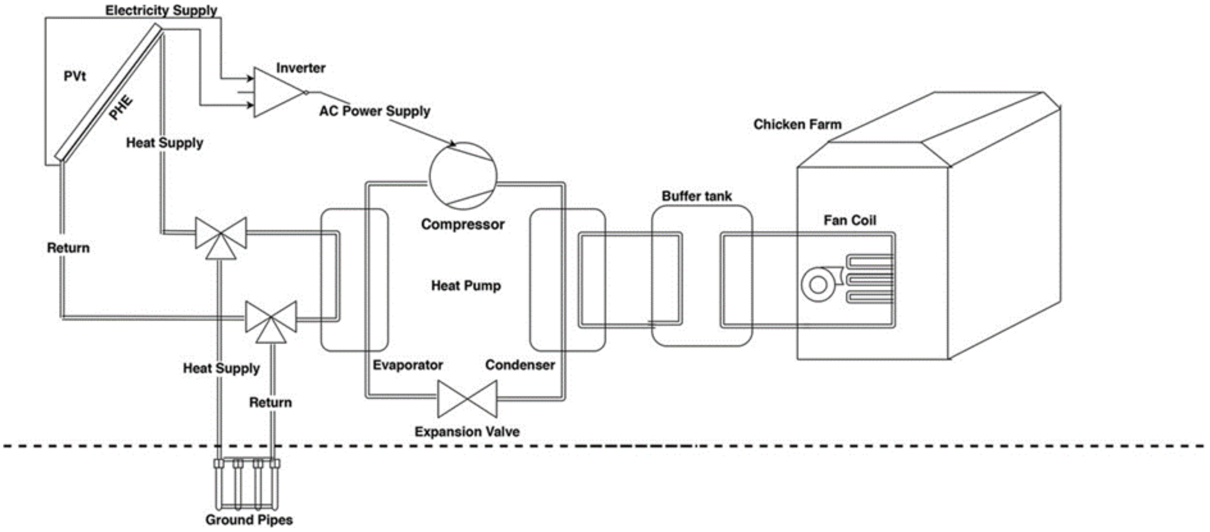
In January 2016, Ghoname, M. S; A.M, EL-Metwally, and T.Z. Fouda conducted experimental work in a commercial broiler chicken barn located in Babel village, Menofia Governorate, with latitude and longitude angles of 30.67°N and 30.98°E, respectively. Their study aimed to assess the performance of a manufactured heating system and its impact on indoor air temperature and energy requirements during the winter season of 2015.Measurements were taken of indoor air temperature above the floor surface, indoor air relative humidity, fuel consumption, heat energy addition, and specific heating power for every cubic meter of house volume, along with specific fuel consumption. Additionally, broiler performance was evaluated in terms of live body mass.The results revealed that using the manufactured heater in the broiler house resulted in a weekly average indoor air temperature ranging between 31.61°C and 23.26°C during the first and fifth weeks, respectively. Concurrently, indoor relative humidity varied between 26.15% and 52.48% at the same ages. The average heat energy addition to the house over the birds' life cycle was 63.28 kW, with a specific heating power of 148.4 W/m3 in the first week, decreasing to 37.07 W/m3 by the fifth week. Heating energy requirements decreased from 422.59 kJ/h.kg in the first week to 19.45 kJ/h.kg by the fifth week, coinciding with an average broiler body mass of 2.2 kg. These findings demonstrate the effectiveness of the manufactured heating system in maintaining appropriate indoor conditions while reducing energy consumption over the broilers' growth period [9].

In the April 1, 2017 issue; Wang, Yang, and Li Baoming state that temperature is the main environmental factor considered to affect poultry performance. Insulation performance of building components is an important factor affecting temperature stability, which is essential to ensure bird health, maximum productivity, and efficient feed utilization. Generally, laying hen houses are not equipped with winter heating systems, and temperatures that meet the requirements of layer hens depend on the sensible heat production of the layer hens. The sensible heat production of the birds and the excellent insulation of the building components is generally sufficient to maintain the poultry house temperature. Low stocking densities and poor building insulation make it difficult to meet the environmental requirements of a layer house, including temperature, humidity, and air quality. Improving the insulation of building components will reduce heat loss, and increasing stocking density will increase sensible heat production. However, an ideal ventilation control system is necessary to keep air pollution emission levels within acceptable limits and to avoid unnecessary ventilation heat loss. The minimum ventilation volume is therefore particularly important. This is crucial for indoor temperature levels and uniformity. The minimum ventilation volume and air flow of a layered house is crucial for the uniformity of indoor temperature and humidity as well as temperature control. However, information on design theory was lacking. We could not find any literature showing the optimal relationship between the insulation performance of layer house components and stocking density in layer house systems in different climatic regions of China. In particular, how to determine the insulation performance of layer house components in different climatic zones was an urgent issue in the field of layer house construction and environmental control. The purpose of this paper is to analyze the minimum thermal resistance of building components in different climate zones in China and to develop a dynamic heat balance model for layer houses according to the laws of energy conservation and quality conservation. The model was developed to determine the insulation performance. Building a dynamic heat balance model of the layer house is important to maintain the temperature of the laying hen house and to maintain a healthy environment for the layer hens. As a result, energy consumption and construction costs can be reduced and guide the design of insulation systems for laying houses. In this paper, a theoretical model of steady-state heat balance for a layer house is developed by theoretical analysis and numerical calculation of the minimum thermal resistance of building components under different climatic regions. The results 1) when the calculated temperatures are -25°C (Northeast China), -15°C (North and Northwest China), and -0°C (Southern Yangtze River, China), the minimum thermal resistances of the walls of the layer chicken house should not be less than 0.778, 0.972, and 0.573 m2 °C/W, respectively; the minimum thermal resistances of the ceiling in the above three regions are 2) The maximum stocking densities and outdoor design temperatures for 3-stage A-frame cages, 4-stage semi-A-frame cages, 4-stage overlap tier cages, 6-stage overlap tier cages, and 8-stage overlap tier cages shall not be less than -14, - 17, -19, -22, and -23°C. In this way, a dynamic heat balance of the layer house can be achieved. The results of this study provided a theoretical basis for the design of an insulation system for a closed layer chicken house. These research results can reduce energy consumption and construction costs and provide a theoretical basis for the insulation design system of the layer house [10].

In their March 14, 2018 study, Xinjie Tong, Se-Woon Hong, and Lingying Zhao addressed the escalating challenge of heat stress in large-scale concentrated layer production. While tunnel ventilation is commonly used to alleviate heat stress, it often creates significant thermal gradients, leading to uneven production performance and health risks for the birds. Understanding the three-dimensional spatial distribution and seasonal variations in the indoor thermal environment of layer houses is essential for evaluating bird comfort and devising effective mitigation strategies. To address this need, the researchers developed a 3D Computational Fluid Dynamics (CFD) model to simulate air velocity, temperature, humidity, and heat stress indices within a commercial layer house. The model's accuracy was confirmed through field measurements conducted during hot, mild, and cold seasons. Analysis revealed that heat stress affected 69.1%, 78.0%, and 18.4% of cages in summer, autumn, and winter, respectively, based on the temperature-humidity index, with ventilation rates of 85.8, 15.5, and 11.7 air changes per hour (ACH) and incoming air temperatures of 26.0°C, 15.0°C, and 2.5°C. Additionally, cold stress was observed in 18.3% of cages during winter due to low incoming air temperatures and inadequate mixing. The findings underscored the need for ventilation system enhancements to mitigate both heat and cold stress, particularly given the potential exacerbation of these issues with climate change. The CFD model developed in this study offers a valuable tool for designing and evaluating new ventilation systems to improve the indoor environment of layer houses [11].

In their March 20, 2018 study, Yang Wang, Weichao Zheng, Haipeng Shi, and Baoming Li highlighted the necessity of supplementary heat in poultry houses during cold climates when birds fail to generate sufficient warmth to maintain adequate indoor temperatures. This supplemental heating accounts for the largest share of building energy consumption. Consequently, there's a growing recognition of the need for enhanced insulation in poultry houses to conserve heat in cold environments. A well-insulated structure enables the maintenance of thermoneutral temperatures primarily through the birds' sensible heat production.The study explored the impacts of stocking density, indoor temperature setpoint, and ceiling insulation on ventilation rate, balance temperature, and thermal resistance using fundamental heat balance equations for livestock buildings. The results indicated that stocking density influences ventilation rate, with a modest decrease of less than 7.1% observed when stocking density increased from 133% to 166% at outdoor temperatures below -35°C. The most significant impact on ventilation rate occurred when stocking density transitioned from 33% to 66%. Indoor temperature setpoint had minimal effect on ventilation rate when outdoor temperatures were below -12.5°C. However, for every 1°C increase in indoor temperature setpoint, there was a corresponding 1.5°C reduction in balance temperature. Additionally, increasing roof insulation from 110 to 400 mm resulted in a 1°C decrease in balance temperature. The study validated its model with measured indoor air temperatures from two commercial poultry houses in North and Northeast China, demonstrating a discrepancy of less than 5% between predicted and measured temperatures [12].

In their June 6, 2018 study, Tugba Gurler, Theo Elmer, Yuanlong Cui, Siddig Omer, and Saffa Riffat addressed the continued reliance on traditional energy sources in the poultry sector despite the availability of abundant renewable energy resources worldwide. They presented the results of a field trial involving an innovative and cost-effective HVAC system design implemented in a poultry house. This system featured two integrated novel components: a polyethylene heat exchanger (PHE) based on a photovoltaic thermal (PVt) array, and an efficient ground pipe array coupled to a heat pump-driven HVAC system. The analysis encompassed the daily electrical output of the PV system and the performance of the heat pump. The experimental findings revealed that during the 7-week growth cycle of chickens, 3733 kWh and 2432 kWh of heat energy were supplied, respectively. Additionally, the coefficient of performance (COP) of the heat pump was calculated for the winter period and ranged between 2.3 and 2.43. The PV system demonstrated the capability to generate 1876 kWh of electrical energy, with the potential to meet the energy requirements of the heat pump during the most energy-intensive period. These results underscore the feasibility and effectiveness of integrating renewable energy technologies into poultry house HVAC systems, offering a promising pathway toward reducing reliance on traditional energy sources and promoting sustainability in the poultry sector [13].



FigI-6: Heating system.

In their August 26, 2019 study, T. O. Tehinse, F. R. Falay, and T. O. Aduewa highlighted the dominance of extensive and semi-intensive poultry production systems, which collectively constitute over 75% of all poultry in Southern Nigeria. Their aim was to design, construct, and assess a thermally controlled solar-heated poultry house.The methodology involved the design and construction of a thermally controlled solar-heated poultry house at the Department of Agricultural and Environmental Engineering Research Farm, Federal University of Technology, Akure, Nigeria. This poultry house comprised seven sections/rooms, with five rooms regulated to maintain five different temperature levels. One of the remaining two rooms served as a control experiment section, while the other served as an observation section. The environmental conditions within the thermally controlled poultry house were monitored and evaluated using a developed and calibrated data logger.The results from the pre-stock test were analyzed graphically using Microsoft Excel software. The findings revealed that the dry bulb temperature in the poultry house ranged from 28.91°C to 40.95°C across the different sections, closely matching the preset temperatures. In contrast, the non-thermally controlled section exhibited less temperature stability, with temperatures ranging from 16.26°C to 24.77°C. In conclusion, the study emphasized the superior temperature stability achieved in the thermally controlled section of the poultry house, with minimal deviation from the preset temperatures. This underscores the effectiveness of the design in maintaining desired environmental conditions for poultry production, offering potential benefits for improving overall productivity and welfare [14].

FigI-7: Front view of the developed poultry house.

FigI-8: Back view of the develop poultry house.

In their September 2019 study, Haytham M Dbouk and Roya Mourad addressed the escalating cost of heating poultry houses, a significant contributor to the overall expenses of food production. Traditionally, farmers rely on fuel and gas heaters to maintain the necessary temperatures for raising chicks. To tackle this issue, they proposed an innovative solution: the solar heated poultry house. This system utilizes solar water heaters as a sustainable alternative energy source, capable of providing the required temperatures for various stages of poultry growth.The key feature of this system is the integration of PRO – Shield, an innovative product designed to address the common issue of overheating faced by solar water heaters. By equipping solar water heaters with PRO – Shield, regardless of their size, type, or brand, the efficiency and lifespan of the system are enhanced, while maintenance and operation costs are minimized. This initiative not only addresses the challenge of heating costs but also contributes to Lebanon's industrial development by fostering an innovative mindset and improving the economic cycle, particularly in the poultry sector.Their study demonstrated the efficacy of the tested system in providing the necessary temperatures for chick rearing during the winter of 2019, with temperatures ranging from 32 degrees Celsius in week 1 to 18 degrees Celsius in week 6. Furthermore, the innovative heating system was shown to reduce heating costs by up to 60% compared to traditional methods. Additionally, notable improvements in health and nutrition outcomes were observed.Overall, the solar heated poultry house with PRO – Shield presents a promising solution to mitigate heating costs, enhance sustainability, and promote economic growth in the poultry industry, offering potential benefits for both farmers and consumers alike [15].

In their October 25, 2019 study, S. Gad, M.A. El-Shazly, Kamal I. Wasfy, and A. Awny explored the utilization of solar energy and climate control systems to achieve enhanced productivity and conversion rates in poultry housing compared to conventional methods. They conducted a thermal analysis of solar heating units and photovoltaic systems to determine their thermal efficiencies. Experiments were conducted using three power operating systems: a flat-plate solar collector combined with electricity, a flat-plate solar collector combined with photovoltaic cells, and a conventional system relying solely on electricity. These experiments also involved varying fan stopping periods (2, 5, and 8 minutes). The performance of the poultry house was evaluated based on factors such as relative humidity, ammonia concentration, poultry production, feed conversion rate, required power, and production cost.

The theoretical analysis indicated that the efficiency of the solar heating system was approximately 71.6%, while the efficiency of the photovoltaic cells was around 12.5%. Experimental results demonstrated that the optimal conditions for enhancing poultry production (2.29 kg) with a favorable conversion rate (1.45 kg feed per kg gain), maintaining low ammonia concentration (13.65 ppm) at the fifth week, and achieving a cost-effective production cost (1.12 US $/kg) were achieved using the power operating system of a flat-plate solar collector integrated with photovoltaic cells, with a fan stopping period of 2 minutes.These findings underscore the potential of integrating solar energy and photovoltaic systems into poultry housing to improve productivity, reduce production costs, and promote sustainability in the poultry industry [16].

In their February 24, 2020 study, Frédéric Coulombe, Daniel R. Rousse, and Pierre-Luc Paradis addressed the challenges faced by poultry farmers in cold climate regions, where propane heating presents both financial and environmental burdens. They proposed heat recovery as a solution to significantly reduce propane consumption by preheating fresh air inflow with stalled air outflow. However, while many studies have focused on improving direct ventilation in broiler houses, little attention has been given to the integration of heat exchangers.The researchers conducted a simulation of an existing broiler house (800 m2) equipped with two air-to-air ductless heat exchangers (0.38 m3s-1 each). They used Computational Fluid Dynamics (CFD) software OpenFOAM to create a 3D steady-state buoyant simulation with an RNG k-ε turbulence model. The CFD model was validated with experimental data from Nielsen (1976).In the reference configuration, the two heat exchangers were aligned in parallel against the northern wall. Three alternative heat exchanger configurations were simulated and analyzed for their ability to provide adequate, uniform velocity, temperature, and air age at bird height. While no configuration entirely avoided excessive air velocities, one configuration (C1) reduced the air age standard deviation from 477 to 179 seconds. Additionally, it increased the surface area with adequate air quality from 55% (C0, reference case) to 72% of the floor area.Despite utilizing the same heating power, temperature differences of up to 2°C were observed in the mean air temperature of broiler zones in different configurations. These findings underscore the potential for improving ventilation performance through careful analysis of heat exchanger positions and their effects on airflow patterns [17].

In their March 20, 2020 study, Nermen A. Radwan, Mustafa M.M., Baiomy M.A, and El-Attar M.Z aimed to utilize solar energy for heating poultry houses, as an alternative to traditional energy sources that are often scarce and costly. They designed and fabricated a prototype at the workshop of the Agriculture Engineering Research Institute (AEnRI) - ARC, with experiments conducted at the Solar Energy Laboratory. The experiment took place during the winters of 2018 and 2019.The prototype consisted of a main frame made from wood (80 cm × 80 cm × 70 cm), with a Trombe wall fabricated from two different materials: bricks and concrete. The dimensions of the bricks wall were 40 cm x 70 cm x 10 cm, while the concrete Trombe wall measured 80 cm x 70 cm x 10 cm. Double glass was mounted in front of the bricks or concrete wall. The ventilation control system included a digital temperature controller, solenoid, moving arm, and fan suction, along with a control unit (data logger). The results indicated that the Trombe wall designed from concrete outperformed the bricks wall. The prototype with the concrete Trombe wall maintained a temperature of 30°C for 13 hours and 55 minutes per day, saving 56.46% of energy consumed compared to traditional methods. Additionally, a 100-watt lamp was programmed to compensate for temperature drops below 30°C for ten hours. The average weight of broilers exceeded the standard, with a 0% death rate. The percentage of carbon dioxide and ammonia in the poultry house air did not exceed the standard ratio, and the relative humidity ranged from 50% to 94%. These findings demonstrate the effectiveness of utilizing solar energy for heating poultry houses, offering potential benefits in terms of energy efficiency, animal welfare, and environmental sustainability [18].

In their study published on September 14, 2020, Essam S. Soliman, Ahmed A. Ali, and Rehab E.M. investigated the impact of different heating systems on various aspects of broiler production and welfare. They aimed to achieve optimum thermoneutral conditions in broiler houses to enhance performance, productivity, and welfare.Two hundred one-day-old female Ross®308 broilers were divided into four groups, with 50 birds each, and placed in four independent rooms (G1, G2, G3, and G4). Each room was supplied with a different heating system: gas-operated, halogen, oil, and portable air conditioner heaters, respectively. The researchers collected a total of 1520 samples, including litter, air, serum, intestinal swabs, breast muscles, and organ samples.The results indicated significant improvements in various parameters in broilers raised with oil and portable air conditioner heaters compared to those raised with gas-operated torch and halogen heaters. These improvements included decreased carbon dioxide and ammonia concentrations, litter pH and moisture percentages, feed conversion ratios, water intake, locomotion, and panting behaviors. Furthermore, there were reductions in alanine aminotransferase, aspartate aminotransferase, urea, creatinine, total bacterial and Enterobacteriaceae counts, as well as E. coli and Salmonella isolation and counts, and cortisol levels.In contrast, broilers raised with oil and portable air conditioner heaters exhibited increased weight gains, performance indices, live weights, feeding and resting behaviors, carcass and organ weights, total protein, albumin, and immunoglobulin concentrations.The study concluded that using advanced and clean heating sources such as oil or air conditioner heaters can effectively meet the microclimatic requirements of broilers without causing stress to the birds. This suggests that adopting these heating systems can lead to improved broiler welfare and production outcomes [19].

In their study presented on October 7, 2020, Tugba Gurler, Theo Elmer, Yuanlong Cui, Siddig Omer, and Saffa Riffat introduced an innovative Ground Source Heat Pump (GSHP) system integrated with a hybrid solar system for photovoltaic solar thermal energy (PVT), specifically designed for poultry farms. Recognizing that farmers are often deterred from implementing GSHPs due to high excavation costs and time consumption, this study aimed to assess the efficiency of a novel heat pump system under various environmental and operating conditions in Kirton, UK.The innovative heating system comprised two main components: a thin-tube solar polyethylene heat exchanger installed between roof tiles and PV panels, and a novel vertical ground heat exchanger to harness heat stored in the soil. The heating system was applied to a poultry house and monitored to evaluate its performance in meeting heating demands over the long term.The study determined that the maximum heating demand of the poultry house was 34.4 MWh/PC, while the minimum was 11.1 MWh/PC. The heat pump generated 15.02 MWh of thermal energy per annum. Notably, the solar PV system effectively covered all of the heat pump's annual electrical energy requirements and even generated an extra 8.74 MWh of electricity exported to the grid. The seasonal coefficient of performance was found to be 3.73 throughout the year.These findings suggest that the novel PVT-GSHP heating system presents a promising solution to reduce fossil fuel consumption in the agriculture industry. Furthermore, by optimizing system controls, the energy savings of the entire system can be further enhanced, potentially offering significant benefits to poultry farmers in terms of both financial savings and environmental sustainability [20].

In 2021, Trokhaniak V.I., Spodyniuk N.A., Antypov I.O., Shelimanova O.V., Tarasenko S.V., and Mishchenko A.V. proposed a modular housing system for poultry, aiming to facilitate high-quality breeding of poultry of different ages simultaneously. The heating system employed in the module consists of panel infrared heaters, designed for localized heating of the technological area. The design dimensions of the module were determined to ensure the qualitative progression of the technological process, particularly regarding the stocking density of poultry.Experimental studies were conducted to assess the temperature regime within the poultry breeding area. It was observed that the body temperature of the poultry remained within acceptable limits, not exceeding 41.5ºC. Furthermore, the surface temperature of the feathers did not surpass 29.1ºC, meeting sanitary and hygienic standards.To gain a deeper understanding of the temperature regime within the module, Computational Fluid Dynamics (CFD) modeling was employed. This modeling allowed for the visualization of velocity, pressure, and temperature fields. The results showed that the air temperature near the poultry in the module reached 18.6ºC, while the average velocity did not exceed 0.75m/s. These findings suggest that the proposed modular housing system, equipped with panel infrared heaters, maintains suitable temperature conditions for poultry breeding, ensuring the well-being and comfort of the birds while meeting sanitary standards [21].

In their study published on August 20, 2021, W. I. Okonkwo, C. O. Akubuo, and C. J. Ohagwu investigated the application of passive solar heating, particularly the Trombe wall system, for brooding day-old chicks in poultry production. They noted the growing interest in passive solar heating due to its capacity to provide thermal comfort and energy savings.The Trombe wall system, known for its simple design, was considered suitable for adoption in animal husbandry, particularly in commercial poultry production systems. The study aimed to design, construct, and evaluate the performance of a passive solar heating system using a Trombe wall for brooding day-old chicks at the University of Nigeria, Nsukka, situated at latitude 6°56’N.The designed poultry brooding house incorporated a Trombe wall system measuring 10 m × 8.08 m with a 0.25 m wall thickness for solar energy collection and storage. The brooding room had a floor area of 80.8 m2, capable of accommodating approximately 2000 broiler day-old chicks per batch for a five-week brooding session.Experimental monitoring was conducted to assess both physical elements and biological performance. Physical elements such as ambient conditions, temperature, and relative humidity of the brooding house were monitored, while biological performance was evaluated using day-old chicks for four weeks in three replicates.Results indicated that the temperature and relative humidity of the brooding room ranged from 28°C to 35°C and 56% to 76%, respectively, with ambient conditions varying between 18°C to 37°C and 45% to 87%, respectively. Solar irradiance during the period ranged from 76 W/m2 to 860 W/m2. Biological performance evaluation revealed that the chicks maintained an average live weight of 786.1g after four weeks of brooding operation, with an average mortality rate of 3%.These findings suggest that the Trombe wall system offers a viable heating alternative for brooding day-old chicks, particularly in regions with unreliable, unsustainable, and expensive conventional heating systems, such as the tropics and cold regions [22].

In their study published on September 24, 2021, Zixin Yang, Yunan Tu, Haoyan Ma, Xiaotong Yang, and Chao Liang introduced a novel double-duct ventilation system aimed at addressing the challenge of maintaining appropriate indoor temperatures in poultry buildings during winter in China. Traditionally, tunnel ventilation systems are commonly used, but they often struggle to maintain adequate warmth, leading to cold stress and reduced production performance in chickens during winter months.To tackle this issue, the researchers proposed a double-duct ventilation system that combines the benefits of an exhaust air heat recovery system with a perforated duct ventilation system. They conducted a comparative analysis of indoor airflow patterns, air temperature distributions, NH3 concentration distributions, and air age distributions between a laying hen building equipped with the novel double-duct ventilation system and a traditional tunnel ventilation system, using computational fluid dynamics (CFD) simulations.

The study's results revealed several key findings:

1. The novel double-duct ventilation system increased the average indoor temperature by 4.4 °C compared to the traditional tunnel ventilation system. This increase was attributed to heat recovery from the exhaust air.

2. The double-duct system reduced the in-homogeneity coefficients of indoor air velocity, temperature, NH3 concentration, and air age by significant percentages, creating a more uniform indoor environment.

3. Despite a heat recovery efficiency of 33.2%, which was relatively modest due to the small heat exchange area, the system exhibited a high coefficient of performance (COP) of 6.4. Additionally, the payback period for the system was estimated to be only about 5 months, indicating its cost-effectiveness.

Overall, the novel double-duct ventilation system was found to enhance ventilation performance and create a better indoor environment at a low cost. The study suggests that this system offers a promising new approach for ventilation design in poultry buildings, providing both a practical method and theoretical guidance for improvement. [23].

In a study dated May 1, 2022, Haoyan Ma highlighted the prevalent use of tunnel ventilation systems in poultry buildings across China, primarily focusing on summer thermal environments. However, little attention has been given to winter conditions. To address this gap, a field test was conducted in a layer breeder building in Handan City, China, to investigate winter thermal environment characteristics and issues systematically. The study employed forty-two measuring points to analysed indoor air velocity and temperature distributions. Evaluation indices included the nonuniformity coefficient and temperature humidity velocity index (THVI). Additionally, computational fluid dynamics (CFD) simulations were used to explore the layout of exhaust fans in tunnel ventilation systems to enhance indoor thermal environments.

Key findings of the study include:

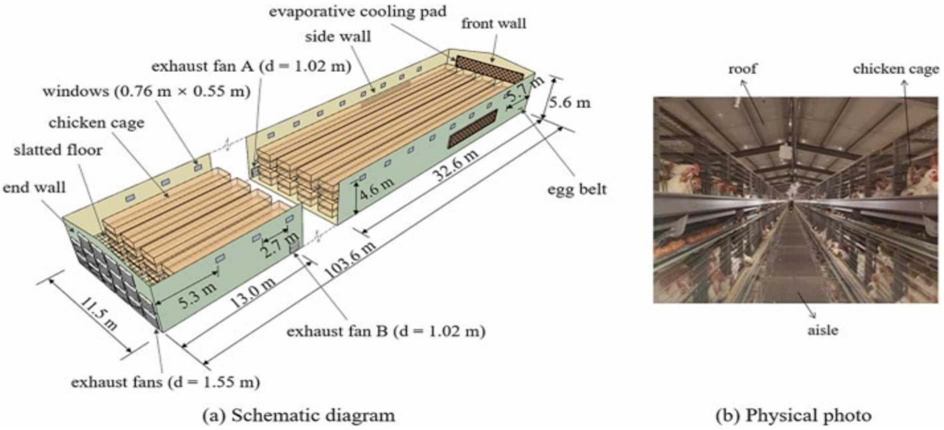
1. Indoor air velocity distribution exhibited significant nonuniformity, with a nonuniformity coefficient of 0.74. The maximum difference reached 0.62 m/s.

2. Nonuniformity coefficient of indoor air temperature distribution was 0.16, with a maximum temperature difference of 12.9°C.

3. The indoor THVI fell below the appropriate range of 18–25, resulting in a thermal comfort zone of only 61.4%.

4. Installing exhaust fans symmetrically at the front and end walls, with appropriate sizes, improved indoor air velocity and temperature distribution uniformities by 22.0% and 88.3%, respectively.

These experimental findings and parametric optimizations provide valuable insights for designing suitable thermal environments for poultry buildings during winter, contributing to improved welfare and performance of the poultry. [24].

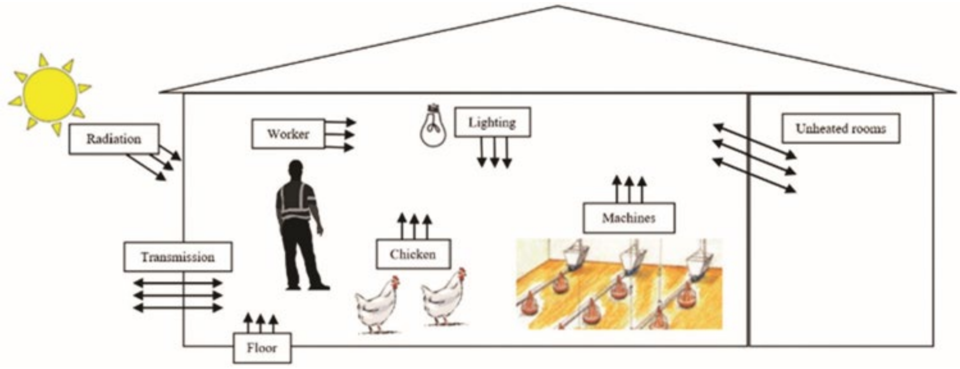


(a) Schematic diagram (b) Physical photo

FigI-10: (a , b)

On June 30, 2022, Yusra Boutira conducted a study on a proposed ground-air heat exchange system aimed at fulfilling the environmental requirements, minimizing energy usage, and lowering greenhouse gas emissions for an industrial poultry facility located in southern Algeria. To achieve this goal, an elaborate mathematical model was employed to assess the thermal demands of the industrial structure. The analysis included a thorough investigation of soil temperatures to determine the optimal depth for installing the earth-air heat exchanger. Subsequently, a parametric and economic evaluation was conducted to determine its specifications and associated costs. Finally, a comparative assessment was made between its performance and that of the existing systems within the industrial farm.The study findings, derived from rigorous experimentation under extreme operating conditions, demonstrated that the earth-air heat exchanger could fulfill 45% and 38% of the heating and cooling requirements, respectively. During summer, the proposed heat exchanger effectively reduced temperatures from 47°C to 27.1°C, while in winter, it elevated temperatures from 4.8°C to 22.9°C. Notably, its performance remained stable compared to the currently employed systems, showcasing superior temperature control, particularly in hot external conditions. Additionally, its implementation resulted in a reduction of CO2 emissions to 719 kgCO2/day during heating and 2531 kgCO2/day during cooling, rendering it a viable solution for such industrial infrastructures [25].

FigI-11: inside view of the poultry house, Salem Poultry Farms, Sidi Okba, Biskra, Algeria.



FigI-12: Energy balance of poultry house.

On December 11, 2022, Masry E. S., M. A. Hassan, Y. S. Abdallah, and K. A. Metwally introduced a novel automatic heating technique designed to enhance performance within poultry houses utilizing renewable energy sources, specifically Biogas energy. The study incorporated four distinct heating systems:

1. H.S1: Conventional heating system employing Liquefied Petroleum Gas (LPG) cylinders with an open direct fire flame.

2. H.S2: Heating system utilizing Biogas energy alongside LPG cylinders with manual conversion to an open direct fire flame.

3. H.S3: Heating system utilizing LPG cylinders with automatic manufacturing heaters and perforated air distribution tubes.

4. H.S4: Heating system utilizing Biogas energy alongside LPG cylinders with automatic manufacturing heaters and air distribution tubes.

The findings demonstrated that the utilization of Biogas energy led to a 3% increase in poultry body weight per bird after 6 weeks and approximately a 4% increase in total body weight, alongside a 10.3% enhancement in Production Efficiency Factor (PEF) compared to conventional systems. Furthermore, the implementation of H.S4 resulted in a significant increase in poultry body weight per bird by 175% and 163% after the first and second weeks, respectively, compared to the initial stages. Over a 6-week period, there was an observed increase in poultry weight per bird by about 30%.The adoption of the new heating system also resulted in an increase in feed intake ranging from 6% to 8% and a decrease in Feed Conversion Ratio (FCR) ranging from 29% to 33%. Additionally, the use of the new system and Biogas energy increased the survival ratio by approximately 6%, subsequently decreasing the mortality rate. Furthermore, there was an 85% increase in PEF compared to conventional systems when employing H.S4.Moreover, the total energy consumption decreased by approximately 53% with the application of H.S4, and there was a significant improvement in Specific Energy Requirements (SER), which decreased by about 66% compared to H.S1 [26].

On February 28, 2023, Ilyas Lahlouh, Driss Khouili, Issam Bouganssa, Ahmed Elakkary, and Nacer Sefiani emphasized the critical importance of indoor air temperature and humidity control in broiler house climate management. They underscored that precise control of these factors is vital for poultry health and production. The primary objective of their study was to develop and evaluate a novel state-space model capable of rapidly predicting the hygro-thermal behavior of livestock buildings. The study involved monitoring various experimental measurements such as ventilation rate, thermal heating, air temperature, and humidity in two commercial poultry houses located in the Mediterranean zone throughout a production cycle under cold conditions. The developed model was estimated and validated using a dataset spanning 25 days and encompassing three different ventilation operation modes (minimum ventilation, power ventilation, and tunnel ventilation). Simulation results demonstrated that the predicted model closely matched the measured data, achieving satisfactory accuracy. The coefficients of determination (R2) averaged 0.93 and 0.95 for the indoor air temperature and humidity models, respectively. Additionally, the root mean squared error (RMSE) was 0.3213 °C for temperature and 0.957% for humidity. Moreover, the predictive model exhibited satisfactory performance for long-term predictions, with a final prediction error (FPE) of 0.084. This capability is valuable as it eliminates the need for time-consuming processes to obtain precise physical parameters related to the poultry house system [27].

I.3. Conclusions:

In conclusion, previous research on heating in poultry houses highlights the importance of providing a suitable thermal environment to ensure the health and growth of poultry. Studies have shown that effective heating systems contribute to improved growth rates, reduced mortality rates, and increased productivity in general. Research has also emphasized the need to choose the appropriate heating system by local climate, farm size and poultry type. Good heating is a critical factor in improving the welfare of birds and avoiding health problems associated with cooling or thermal inequalities. The future of research is geared towards developing more efficient and sustainable heating solutions that contribute to reducing operational costs and achieving more environmentally friendly agricultural practices.

Chapter II

State of the art: Heating systems for poultry.

II.1. Introduction :

Providing optimal heating conditions in poultry houses is crucial for the well-being and growth of the birds. At the beginning of their life cycle, chicks require warmth, typically around 35°C, and are highly sensitive to drafts.[28] As a result, it's essential to ensure that the building is adequately heated, with a focus on preventing sudden air inflows that could cause discomfort or stress to the chicks. Conversely, as chickens reach the finishing stage, they require cooler environments.

In addition to temperature regulation, understanding the factors influencing internal conditions within the poultry house and the mechanisms of heat transfer is vital for effective management. Factors such as external weather conditions, insulation levels, and building design can all impact the indoor climate.

Heat transfer mechanisms play a significant role in maintaining optimal temperatures within the poultry house. These mechanisms include conduction, convection, radiation, and evaporation. Understanding how heat moves within the environment allows farmers to implement appropriate heating systems and ventilation strategies to meet the birds' physiological needs at different stages of development.

Therefore, as the physiological requirements of chickens vary throughout their growth stages, it is imperative to tailor the building's environment accordingly. Proper ventilation management through the implementation of efficient control systems is essential to ensure that the poultry house maintains the desired temperature and air quality, promoting the health and productivity of the birds.

II.2. Heat stress in poultry :

Heat stress in poultry refers to the discomfort and negative health effects experienced by birds when exposed to high temperatures or inadequate cooling mechanisms. This stress can have various impacts, including reduced feed intake, decreased egg production, impaired immune function, and increased mortality rates. Several factors contribute to heat stress, including high ambient temperatures, high humidity levels, poor ventilation in poultry houses, and inadequate access to water.

Effective heat regulation plays a crucial role in mitigating heat stress in poultry. Proper ventilation systems, access to shaded areas, and ensuring an adequate supply of clean, cool water can all help alleviate heat stress and maintain optimal conditions for poultry health and productivity.

Among these measures, heating systems also contribute significantly to reducing heat stress, particularly during colder seasons. Heating systems help maintain a stable and comfortable environment for the birds by providing warmth when ambient temperatures drop. By ensuring that poultry houses are adequately heated, without sudden fluctuations in temperature, heating systems help mitigate the risk of heat stress during periods of cold weather. Properly regulated heating systems play a key role in creating a balanced indoor climate that promotes the well-being and productivity of poultry while reducing the incidence of heat stress.

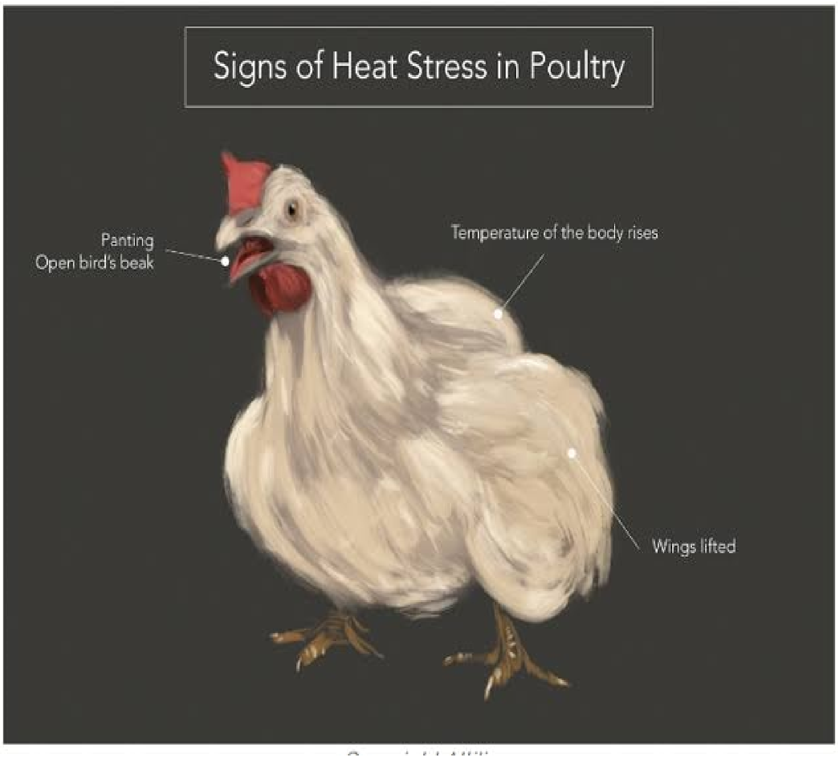


Figure II.1: The effects of heat stress

II.3. POULTRY LIVING ENVIRONMENT :

Understanding the influence of indoor climatic conditions in poultry houses on birds, their reactions, and the implications for heat management in poultry production is paramount. This data is crucial for designing open-air poultry houses that mitigate heat stress and ensure optimal chicken production, particularly in arid regions. Factors such as temperature, relative humidity, air composition, airflow, and lighting conditions all play significant roles in shaping the climatic environment and must be carefully considered in architectural design requirements.

II.3.1. Temperature:

At the start, chicks need warmth (35°C) and are sensitive to drafts. The building must be adequately heated, without sudden air inflows. Conversely, finishing chickens require coolness. In hot weather, high air speeds (about 1 meter per second) at their level are necessary.[28]

Therefore, the physiological needs of the chicken vary during rearing according to age, and the building must meet each requirement. Properly managing ventilation through efficient control systems is essential. The table below (Table 1) represents the recommended temperature for raising poultry.

Table II.1: Temperature standards [28].

Age	Temperature below the Heating	Temperature of the living area
first days	38	> 28
first week	35	28
second week	32	28
third week	29	28
fourth week	25	25

Maintaining the ideal production temperature in the tropics is difficult, thus the poultry house designer must pay close attention to temperature variation.

II.3.2. Relative humidity:

Oloyo observed that when the internal temperature exceeds 26.7°C along with high relative humidity, there is a notable decrease in feed efficiency, feathering, pigmentation, and weight gain in chickens.[29] In addition, regardless of fluctuations in relative humidity, the performance of birds was adversely affected within an internal temperature range of 35–37.8°C. This indicates that elevated humidity levels may aid in enhancing bird performance at lower temperatures. However, it's essential to manage humidity carefully as it can create a conducive environment for microbes, thereby increasing the risk of illness for the birds.[30,31]

Temperature and relative humidity are closely interrelated. During the brooding period, especially in the early weeks, internal relative humidity may be low or excessively low due to the heat required by the chicks at that age or when they are thirsty or hatched at a higher temperature. The water vapor released by the evaporative cooling process of the chickens, as they regulate their body temperature during growth, leads to a rapid increase in internal relative humidity.[32] Consequently, the third week and beyond are pivotal stages in chicken production, regardless of the bird class.

According to Oloyo [29] laying birds require relative humidity levels of 60–80 percent during brooding and 50–70 percent following brooding for optimal success.

II.3.3. Air composition:

The decomposition of bird feces gives rise to harmful and pollutant gases, including ammonia, carbon dioxide, methane, and hydrogen sulfide, among others. Due to their detrimental effects on bird performance, poultry facilities, human health, and the environment at large, these gases are a significant concern.[32] As a result, for optimal chicken production, ammonia and carbon dioxide concentrations of 25 ppm and not more than 2500 ppm were suggested [30, 33].

Removal of fecal waste from the poultry house should be done often to limit the amount of gas emission for optimum bird health management

Figure II.2: Air installation in poultry houses.**[34]**

In an enclosed structure where poultry is confined, air composition undergoes changes if proper ventilation is not maintained. Carbon dioxide, ammonia, and other harmful gases can reach dangerously high concentrations. Table .2 outlines the critical and ideal levels of certain gases identified in the study. The ventilation system plays a crucial role in replacing the air in the building, ensuring an adequate supply of oxygen for survival while eliminating toxic gases and odors produced by respiration and waste decomposition. Additionally, the system helps to reduce the concentration of disease-causing pathogens in the air, maintaining a safe environment for the birds' health.

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

Gaz	Symbol	Lethal	Désirable
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_2S	Above 500ppm	Below 40ppm
Oxygen	O_2	Below 6%	Above 16%

Ventilation is essential to remove excess moisture from homes. Adequate ventilation reduces relative humidity, promotes better health, and prevents moisture condensation on walls and ceilings. Heat causes air volume to expand, enabling it to hold more moisture. A rise in air temperature by approximately 20°F doubles the moisture-holding capacity of air.

II.3.4. Air velocity:

Varied air velocity within the chicken house can contribute to reducing high internal temperatures to a certain extent. Moreover, air velocity plays a significant role in convectional cooling and managing air quality. [35,30] It is suggested that the ventilation capacity in hot climates be at least "5m3 per chicken each hour, with inlets averaging 1.5cm2 per m3 ventilation"[32] According to Hulzebosch [30] According to [reference], in temperatures ranging from 25 to 30°C, it is advisable to maintain a still air velocity of 0.1–0.2 m/s. Similarly, Lacy and Czarick[36] found that broilers grew faster at 2 and 3 m/s air velocity, respectively.

The study took into account the ages of the chickens within a temperature range of 25–30°C while varying air velocity to better comprehend its impact on the birds. The research found that increased air velocity of 2 and 3 m/s benefited 6-week-old broilers more than 4-week-old broilers. This difference in effectiveness may be attributed to the higher warmth requirements of younger birds during the brooding period.

II.3.5. Lighting:

The lighting during early stages of life has minimal or negligible impact on the hormone system in birds; instead, it primarily enhances their activity, encompassing feed intake, development, and both physical and physiological activities. [37,38] may result in fatigue, cannibalism, immunological reactions, limb deformities, and even mortality [38,39,40]

The continuous illumination scheme of 16 hours light and 8 hours darkness is widely utilized and has been shown to improve overall chicken performance [37]
However, intermittent illumination, which alternates short periods of light and shade, has been shown to improve chicken performance.[32]. At the post- hatch period (1–7 days old), a continuous illumination program with a minimum light intensity of 20 lux is advised to help the chick adjust to their surroundings and improve eating [38]. As a result, the light intensity is decreased to 3–5 lux, and an intermittent lighting system is implemented for simple regulation of the birds' activity, resulting in improved performance and production [32, 38].

Figure II.3: poultry house lighting.[41].

II.4. Thermal regulation of chickens :

Excess body temperature is eliminated through four different mechanisms:

II.4.1.Convection :

Body heat is dissipated into the cooler ambient air. Birds will increase their exposed surface area by lying down and spreading their wings. This convection is facilitated by the air velocity in the building**..[42]**

Vasodilation - The influx of blood into the combs and wattles allows for the dissipation of body heat.

II.4.2 Rayonnement :

Through electromagnetic waves, body heat is radiated towards cooler areas in the building (walls, ceiling, equipment).**[42]**

II.4.3.Refroidissement par évaporation :

Rapid breathing with an open beak increases heat loss by enhancing the evaporation of water from the mouth and respiratory tract. Cooling by evaporation is facilitated by lower air humidity..**[42]**

II.4.4.Conduction :

Loss of body heat towards cooler materials in direct contact with the chicken (bedding, wire mesh, metal equipment). Birds will seek cooler spots in the building**.[42]** Birds lie down on the floor and dig into the bedding to find a cooler spot.

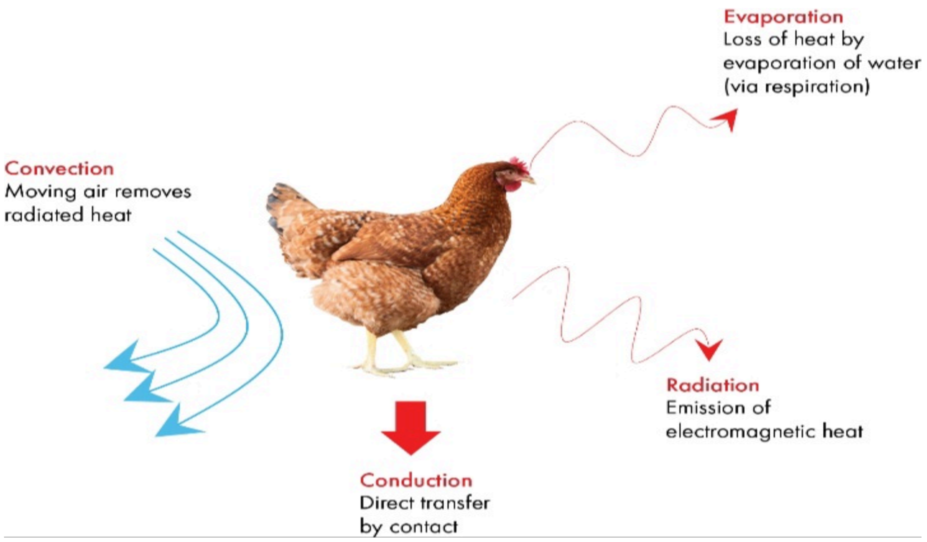


Figure. II4: Heat transfer of poultry [43]

II.5. .Types of heating systems :

Choosing heating systems for poultry houses requires consideration of factors such as energy efficiency, reliability, suitability for house design and the needs of the birds.

II.5.1. Novel hybrid heating system: PVT-GSHP:

A heat pump was designed to provide part load of the poultry house’s annual energy demand to evaluate the novel hybrid system performance under the real site condition. The 15 kW HP was selected based on the thermal energy collecting from solar and soil on the available spaces in the farm. Besides, existing gas boilers in the chicken house were used to back-up the HP for days requiring particularly high heating energy|[44]. The novel solar-based GSHP design has three design characteristics that aim to address the issues of size of the PHE and ground pipe arrays (novel vertical and commercial horizontal) and heat transfer amount of each component, the whole heating system’s thermal and electrical.

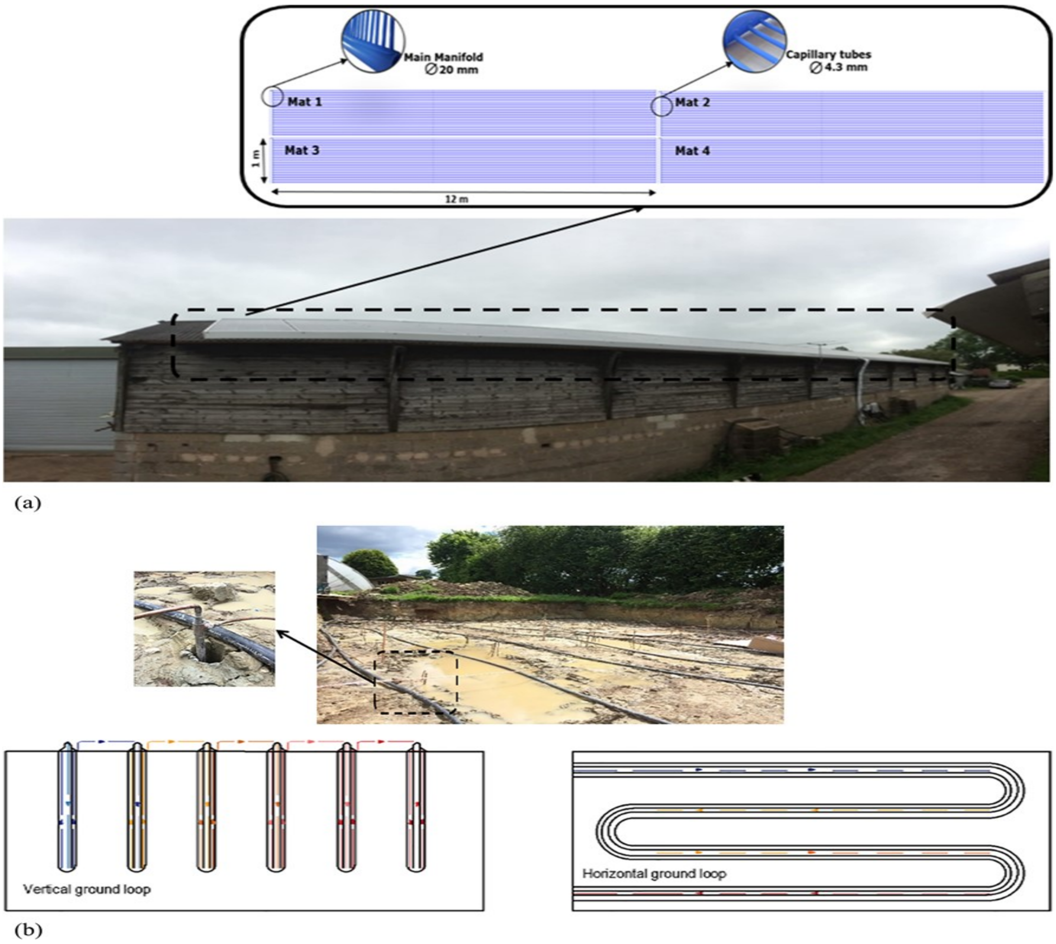


Figure II.5: The picture of the components (a) PVT array and (b) ground array [44]

The main objective of the study is to show advantages of using novel solar PHE and copper VGHEs attached to the heat pump because these PHE and copper VGHE are easy to apply underneath the PV panels and underground, respectively. A summary of the design and technical information of the numbered components of the heating system are given in Table 2. The schematic drawing and the picture of the novel PVT-GSHP system is presented and numbered in Figure 3a and b.[44]

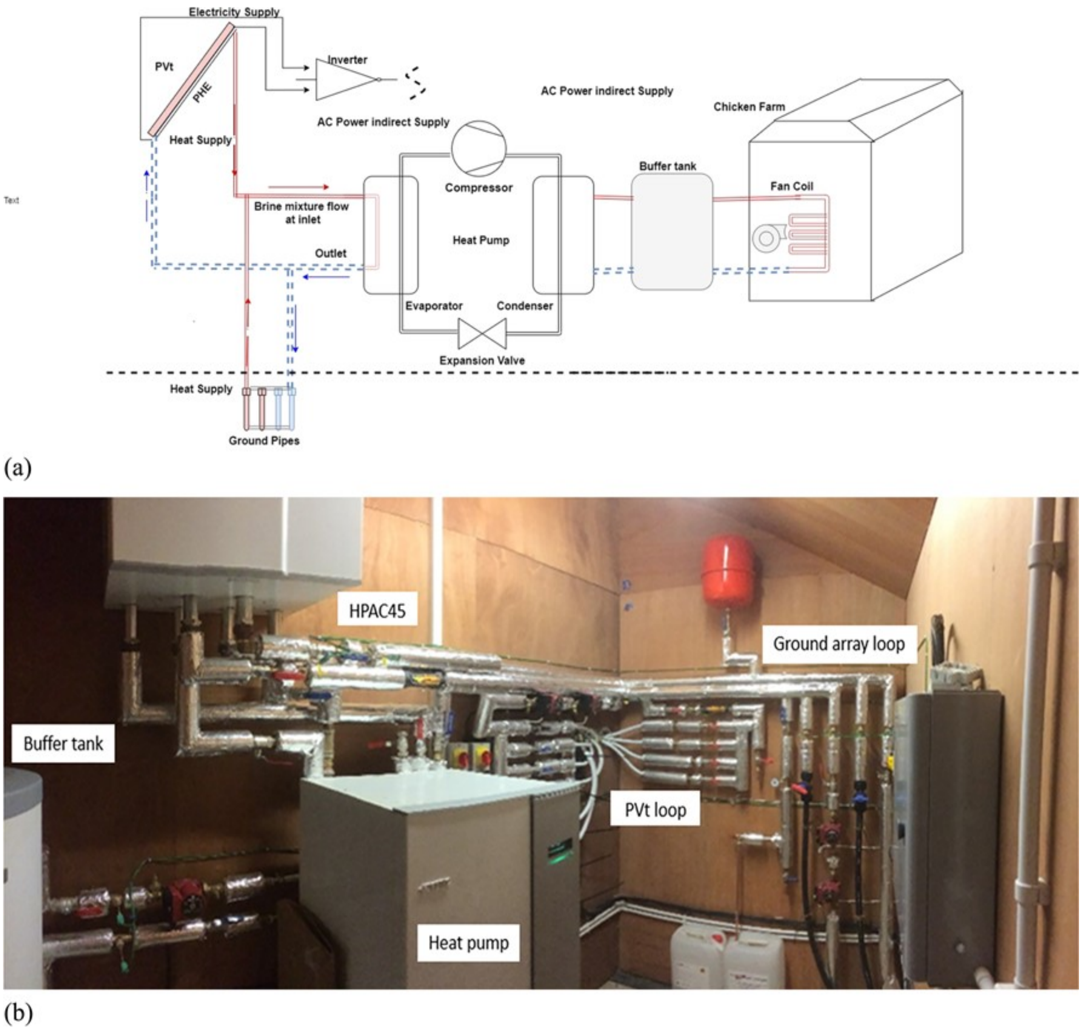


Figure II.6: The hybrid heating system (a) schematic and (b) labelled picture.**[44]**

II.5.1.1. METHODOLOGY:

a) System design and performance assessment:

The novel solar-based GSHP design has three design characteristics that aim to address the issues of size of the PHE and ground pipe arrays (novel vertical and commercial horizontal) and heat transfer amount of each component, the whole heating system's thermal and electrical energy output and its operating time and the energy needs of the chicken farm. The indoor temperature is maintained with heat pump and gas boilers during the peak heating season. Figure7 presents the system design and control. The indoor temperature is maintained with heat pump and gas boilers during the peak heating season. The PVT-GSHP system consists of five subsystems. The first subsystem is PHE ground loop for heating the circulating water. Heated water by the sources is mixed and used as a heat source for the heat pump unit. The second subsystem is heat pump device.[44] It is a water source heat

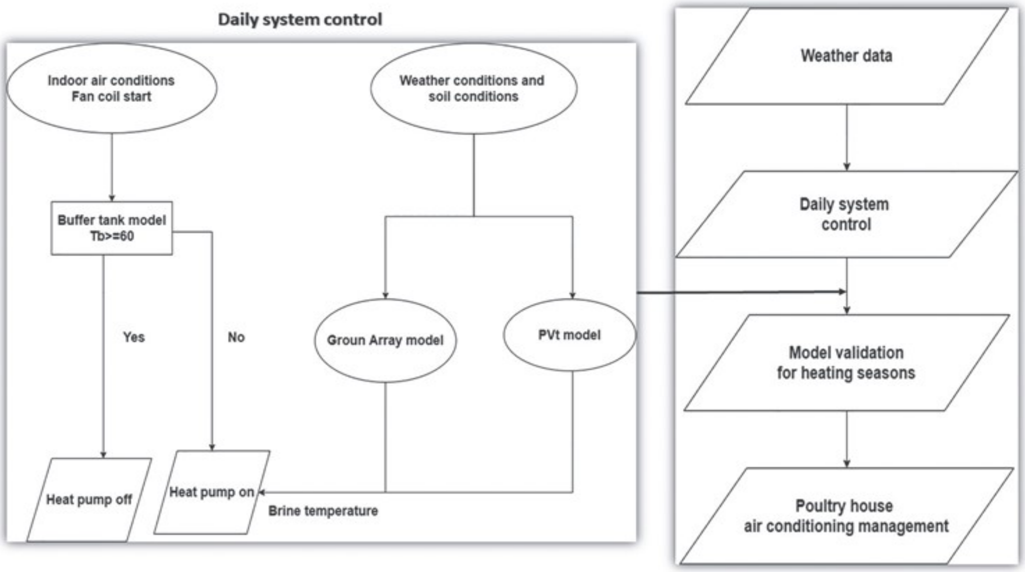


Figure II.7: Basic schematic diagram of system control: one operation mode.[44]

II.5.2. Geothermal energy:

Geothermal energy, stemming from the Greek words "geo" (earth) and "therme" (heat), refers to the warmth generated deep within the earth. Given that heat is perpetually generated underground, geothermal energy serves as a renewable energy reservoir. It finds application in both household heating and energy generation processes.

Figure II.8: Geothermal energy.

Geothermal energy is now one of the most energy-efficient technologies accessible, providing the following benefits:

- can heat and cool sheds.
- almost zero carbon emissions.
- highly scalable.
- may slash energy costs by between 50% and 70% .

- base-load energy is not reliant on sunny skies or windy days.

Geothermal heating and cooling entail the use of steady heat (geothermal energy) that exists two to three meters under the surface for heating and cooling.[45]

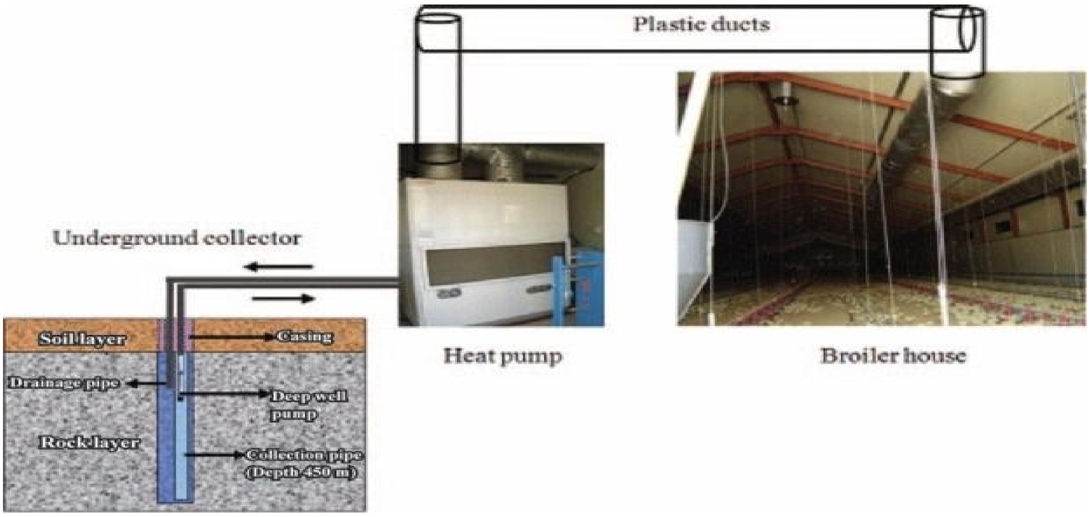


Figure II.9: Schematic diagram of the geothermal heat pump (GHP) system for the broiler house.[45]

II.5.2.1. Working principle of geothermal energy:

In different regions of Algeria, the temperature of the soil typically remains relatively stable throughout the year, ranging from approximately 22° to 24°C at a depth of two to three meters below the surface. To harness this consistent heat energy, a geothermal heating and cooling system utilizes a loop system of underground pipes filled with a fluid. This ground loop collects heat energy and conveys it to a heat pump. Subsequently, the heat pump compresses the heat and disperses it throughout the chicken house, extracting warmth from the structure and circulating it back into the ground via the same loop system.[46]

a) II.5.2.2The main components of a geothermal energy system:

A heat pump is an electrically powered device that extracts heat from a place with a lower temperature (source), and delivers it to a place with a higher temperature (poultry houses). The same working principle applies to the cooling pump, where it extracts heat from a place with a higher temperature (the ground) and delivers it to a place with a lower temperature.[47]

A ground heat exchanger and a heat pump are the two primary components of ground- source heat pumps. Unlike air-source heat pumps, which have one heat exchanger outdoors, ground-source heat pumps have one heat exchanger within the residence.[48]

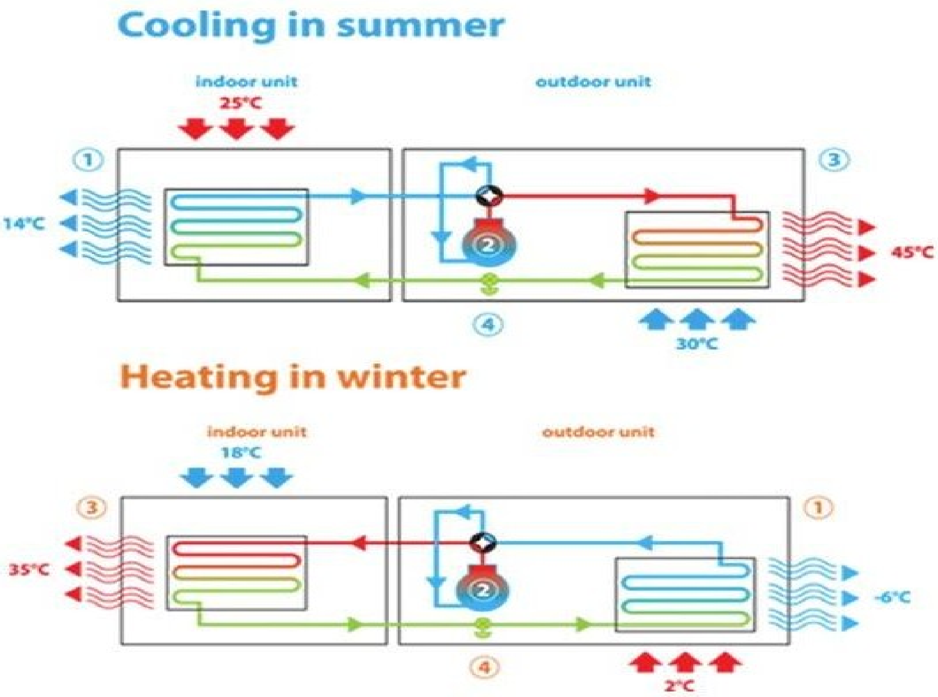


Figure II.10: The heating and cooling pump.[**49]**

II.5.2.3 Ground heat exchanger:

There are two types of ground heat exchanger designs:

b) **Open Loop:**

An open-loop system utilizes a groundwater bore as its heat source. In this system, groundwater is drawn into the heat pump unit, where heat is extracted before the water is safely discharged, ensuring ecological sustainability. Groundwater bores prove to be an excellent heat source due to the consistent temperature they maintain throughout the year.[50] Open systems harness the heat stored in subterranean water bodies. Water is extracted from the well and routed directly to the heat exchanger for heat extraction. Subsequently, the water is discharged into a surface water body, as illustrated in Figure 11.[50]

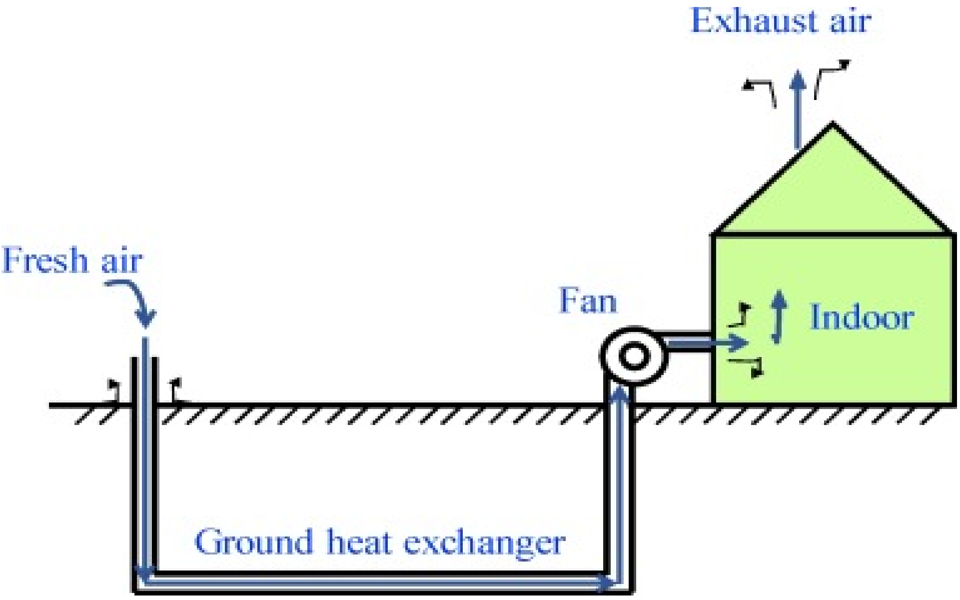


Figure II.11: open loop system.**[50]**

c) Closed Loop:

A continuous loop of underground polyethylene (poly) tubing is used in a closed loop system. The pipe connects to the internal heat pump to create a sealed subterranean loop that circulates an ecologically friendly anti-freeze and water solution. Unlike an open loop system that uses water from a bore, a closed loop system continually recirculates its heat-transferring solution in a pressurized chamber.[51]

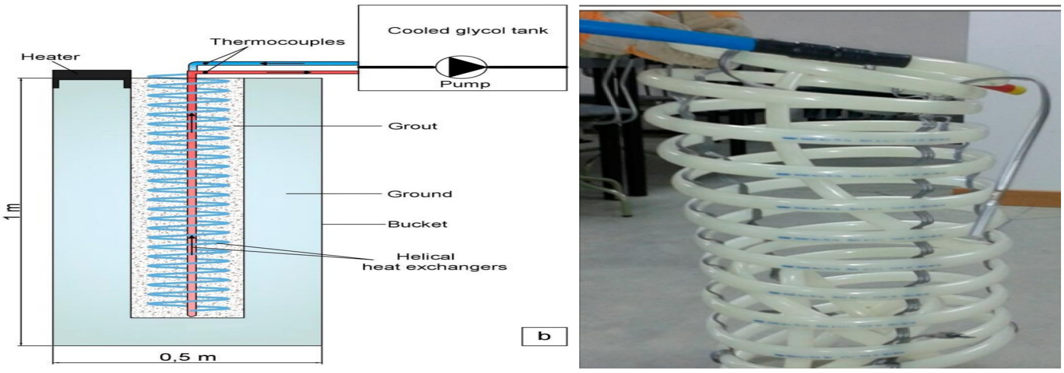


Figure II.12: spiral closed loop system.**[51]**

The temperature, available soil and ground conditions, and local installation costs all factor into the choice to use an external piping system.

II.5.2.4 heat distribution in geothermal energy hvac :

The pivotal components of an HVAC system are the geothermal unit and the distribution system. Responsible for transferring heat from one area to another, the geothermal unit plays a crucial role. Subsequently, the energy generated by the geothermal unit is dispersed throughout the poultry house via the distribution system.[52]

The distribution system offers various configurations to accommodate different needs. The forced-air/ductwork system, commonly used for air cooling, stands as the predominant type of geothermal HVAC system. Additionally, alternatives such as radiators, radiant flooring, fan coils, and baseboard heaters serve as effective solutions for heat distribution.[**52]**

The use of heating in poultry houses is necessary and very important in raising broiler chickens, for example in the Figure 13**.[52]**

Figure II.13: Heating distribution system in poultry house**.[52]**

II.5.2.5. The Geothermal Pump Work:

A heat pump is a device designed to transfer heat from one location to another, utilizing minimal energy. While heat pumps are frequently employed to extract warmth from the earth for heating chicken houses, they can also serve to cool them. Understanding how an air conditioner operates provides insight into the functionality of a heat pump, as the two systems share many similarities in their operations.[46]

Considering that the earth's temperature typically ranges between 20 to 25 degrees Celsius at a depth of 4 meters, and external temperatures can soar between 38-40 degrees Celsius, accounting for geographical orientations and elevation angles in both summer and winter becomes crucial. Naturally, maintaining suitable temperatures for poultry, whether cooler or warmer, throughout the seasons remains imperative.[46]

Heat pumps elevate temperatures from 20 to 38 degrees Celsius, with certain commercial units capable of reaching temperatures of up to 93°C. This process is facilitated by the evaporation, compression, condensation, and expansion cycle inherent to heat pumps. Within the heat pump, a heat transmission medium referred to as refrigerant circulates to facilitate this temperature modulation.[46]

The process initiates as chilled liquid refrigerant courses through a heat exchanger, known as the evaporator, where it absorbs heat from a low-temperature source like ground loop fluid. As the refrigerant absorbs heat, it undergoes evaporation, transitioning into a gaseous state. Subsequently, the gaseous refrigerant is compressed within a compressor, elevating its temperature to around 82°C. This heated gas is then conveyed into the house, reaching approximately 38°C following its passage through a cooled air heat exchanger. Upon losing heat, the refrigerant condenses back into a liquid state. [46]

When the fluid passes through the expansion valve, it cools down and the process repeats. The flow of the system is reversed to act as an air conditioner.

II.5.2.6. How viable is geothermal heating

The El-Oued region experiences a cold winter climate and hot, dry summers. Poultry farms in this area primarily rely on fossil fuels and gas as their main energy sources, which account for a significant portion of the expenses incurred by farm owners, particularly during the colder seasons.[48]
As a result of heating needs, poultry farmers spend approximately 6% of the overall production cost during winter and 4% during summer. According to the study, barns were heated using heat lamps and a diesel boiler, while ventilation depended on evaporative cooling principles, utilizing fans.[53]

Figure II.14: Poultry houses in El-Oued state.

II.5.2.7. Efficiency of geothermal energy system in poultry houses:

Geothermal energy holds promise as a cost-efficient heating solution for highly productive chicken buildings. The exchange of heat between the soil and the chicken house proves more effective compared to previous alternatives, owing to the soil's relatively stable temperature.[54]

Utilizing a ground source heat pump (GSHP), heat is efficiently extracted from the soil to heat the chicken shed, ensuring optimal production performance [55]. This approach not only maintains the desired indoor temperature for the poultry shed but also reduces fuel requirements and CO2 emissions. In a specific example, [56] developed a GSHP system for heating a poultry house in Algeria. Their findings indicate that the GSHP system significantly reduces operating costs by efficiently harnessing heat from the ground to warm the shed. Approximately 82% energy consumption savings were achieved compared to conventional poultry houses during the operational period.[49]

Figure II.15: Saving consumption when using GHP.

In addition, the mortality rate of broilers when using the geothermal energy system reached 3% of the total number of poultry, compared to the traditional systems, which amounted to 6% of the total number of chicks.

II.5.3. New automatic heating system by renewable energy:

II.5.3.1.MATERIALS AND METHODS:

The present study was conducted under uncontrolled environmental conditions in broiler houses located in the poultry farm in Kafr Saqr district, Sharkia Governorate, Egypt, to evaluate the performance new heating system for poultry farms using biogas as a renewable energy source compared to conventional method. An experiment was carried out through two successive winter seasons (December- February) of 2017/2018 and 2018/2019. Chinese Biogas plant was constructing, testing and operating to produce Biogas as a renewable energy source to use for heating poultry houses.[57]

II.5.3.2. Experimental Design (Experimental Procedure):

Four experimental groups were carrying out at the poultry farm to evaluate the four different heating systems Fig. 1 within poultry houses. The four different heating systems were as follow :

1- H.S1; Conventional heating system using fossil fuel source (the cylinder of Liquefied

Petroleum Gas LPG) with open direct fire flame.

2- H.S2: Heating system using Biogas energy and the cylinder of Liquefied Petroleum Gas LPG with open direct fire flame manual converting)

3- - H.S3: Heating system using the cylinder of Liquefied Petroleum Gas LP G with the automatic manufacturing heater and air distribution perforated tube.

4- - H.S4: Heating system using Biogas energy and the cylinder of Liquefied Petroleum Gas LPG with the automatic manufacturing heater and air distribution perforated tube.

All other traditional practices for poultry breeding were applied for all young and old chicken were applied, like ventilation, health care, feeding, drinking, and vaccinate recommended. All experiments were carried out every week from 2 to 6 weeks of age. Sufficient samples were taken to determine the all-experimental measurements. The poultry houses were prepared with optimum environmental conditions are (Air velocity was 2 m.s-1 - Ambient temperature (variable according age of broiler, starting degree was about 32˚C, then decrease 2 ˚C weekly).[57]

Fig. II.16. Photos of heating system components inside the shed: a) Open direct fire flame, b) Airdistribution perforated metal tube.[57]

II.5.3.3. Materials

- **Shed Characteristics**

The poultry shed consists of four groups,each one consider as one house with area about 40 m^2 has 400 birds for each, and stockingcapacity 10 $bird.m^{-1}$.[57]

- **Chinese Biogas Plant**

Chinese Biogas plant was constructing according previous research recommendation to produce biogas using as a new energy source to heating poultry houses. Basic components of theChinese biogas model Fig. 2 and Table 1.[57]

II.5.3.4. The new automatic manufacturing heater

The new automatic manufacturing heater shown in Fig. 3 can use a fossil fuel (LPG) and Biogas energy which produce from digester, using alternative device. The new heater contains separating chamber "attached chamber"have broiler used to heating air inside closed pipes-Metal pipes and some valves, used to transfer hot air from heating zone to inside poultry house. The heater was constructed from local material witch available in the Egyptian market. About 10% of the components are imported and available in the market, is consisted of four standard gas burners, 60 cm length, contained in an insulated steel cylinder, 40 cm diameter and 90 cm length. The cylinder has bottom holes to allow the fresh air in and a chimney to discharge the exhaust gases. An eccentric 10 cm diameter stainless tube, 2 mm thickness and 110 cm length, is passing through the upper part of the insulated cylinder to carry.[57]

the air to be heated. The heater is equipped with a pilot light to keep the fire on during heat shut down according to the sensors signals. The unit has a 20 cm diameter air blower operated by a 2- phase electric motor, rated power is 0.25 kW. (Table 2). It was controlled in the hot air flow rate through the system, the blower flow rate. Thus, a speed controller is used to reduce the blower air speed. This heater is operated using many different energy sources from LPG, new and renewable sources (Biogas). The air is heated by two sources of energy, one of which is LPG and Biogas. Three solenoid valves were connected to the gas inlet to allow switching between LPG and Biogas according to a signal from the thermostat [57]

The three electric valves (Selnoid valves), all of which are installed on the heater outside the shed, and each of them is connected to a thermal thermostat inside the shed, through which the heater is turned on and off, as well as switching between the gas produced from the Chinese biogas plant and liquefied gas automatically, according to the optimal temperature required for the bird.

A line of metal tubes connected to the heater inside the shed. Air distribution perforated tube It has four openings, each with a distance of 90 cm. A pipe is installed on each of them heading towards the floor of the shed. At the end of each of them is a metal valve who’s opening and closing are controlled manually to control the space of the shed according to the age stage, so that all openings are open at the end of the fattening cycle.[57]

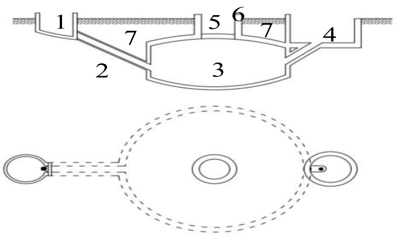


Fig. 1. Chinese biogas digester model

Table 1. Basic components of the Chinese biogas model

Part	Name
1	Mixing Pit or Inlet
2	Inlet pipe
3	Digester/Gas Storage
4	Outlet Chamber
5	Removable Manhole
6	Gas Outlet Pipe
7	Backfill

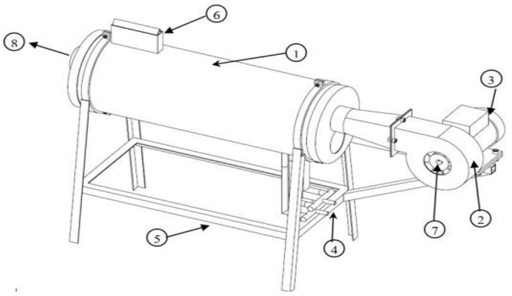


Fig. 2. A new automatic manufacturing heater presented by (Abd-Allah *et al.*, 2022)

Table 2. Basic components of a new automatic manufacturing heater

Part	Name
1	Insulated galvanized cylinder
2	Air blower
3	Electric motor
4	Gas burner
5	Frame
6	Chimney
7	Air inlet
8	Hot air outlet

Measurements

Body weight

At the end of each experiment 5% of birds weighed as group. The total weight is divided by the number of weighed birds.

Feed intake (FI)

$$\mathrm{FI} = \frac{\text{Total consumed feed}}{\text{No. of birds}}$$

Feed conversion ratio (FCR)

$$FCR = \frac{\text{Feed intake, Kg}}{\text{Body weight gain, Kg}}$$

(**Wagne e*t al.,* 1983**).

Mortality percent (%)

$$\text{Mortalitypercent (\%)} = \frac{\text{Number of dead birds}}{\text{Totalnumber of birds.}} \text{x}100$$

(**Halpin, 1975**).

Survival rate: =

$$\frac{\text{Total no. of birds} - \text{No. of dead birds}}{\text{Total no.of birds}} \times 100$$

Production efficiency factor (PEF)

It was calculated according to **Samarakoon and Samarasinghe (2012)**

$$\mathrm{PEF} = \frac{\text{Body weight gain (kg)} \times \text{survival rate (\%)}}{\text{Age of depletion (day)} \times \mathrm{FCR}} \times 100$$

Total heat energy

kJ = Amount of fuel consumption, kg * Fuel calorific value, kJ. Kg^{-1}

The calorific values of 50 and 40 MJ. Kg^{-1} for LPG and Biogas respectively.

Specific energy requirements (SER)

$$\mathrm{SER} = \frac{\text{Total heat energy ,MJ}}{\text{Total poultries body ,kg}}$$

(**Ali *et al.,* 2011**)

II.5.4. Solar collector technology:

Solar thermal collector technology presents an attractive option for heating poultry houses due to its energy efficiency and cost-effectiveness compared to traditional resources such as liquid petroleum gas (LPG).[58,59]. Essentially, a solar thermal collector system integrated into a roof can satisfy up to 80% of the energy demand for poultry. Presently, this technology is widely employed in various agricultural applications, including solar dryers.[60], solar greenhouse [61], solarpump, dairy processing plants [62], solar heating [63] Additionally, solar thermal energy is harnessed through solar hot water systems (SHWS) or solar air heater systems (SAHS). SHWS, which utilizes solar radiation to produce hot water, is well-established and has found application in poultry houses. Various configurations exist for this purpose, categorized into active SHWS and passive SHWS. These configurations include flat plate solar thermal collectors, concentrating solar thermal collectors, and evacuated tube solar thermal collectors. Among them, flat plate solar collector units are most prevalent due to their affordability and ease of design and installation.[64].. The active typeis more complicated and expensive than the passive type, whereasthe efficiency of active SHWS types is normally 35–80% superior to the passive SHWS types [65]. Some recent studies [66–67]

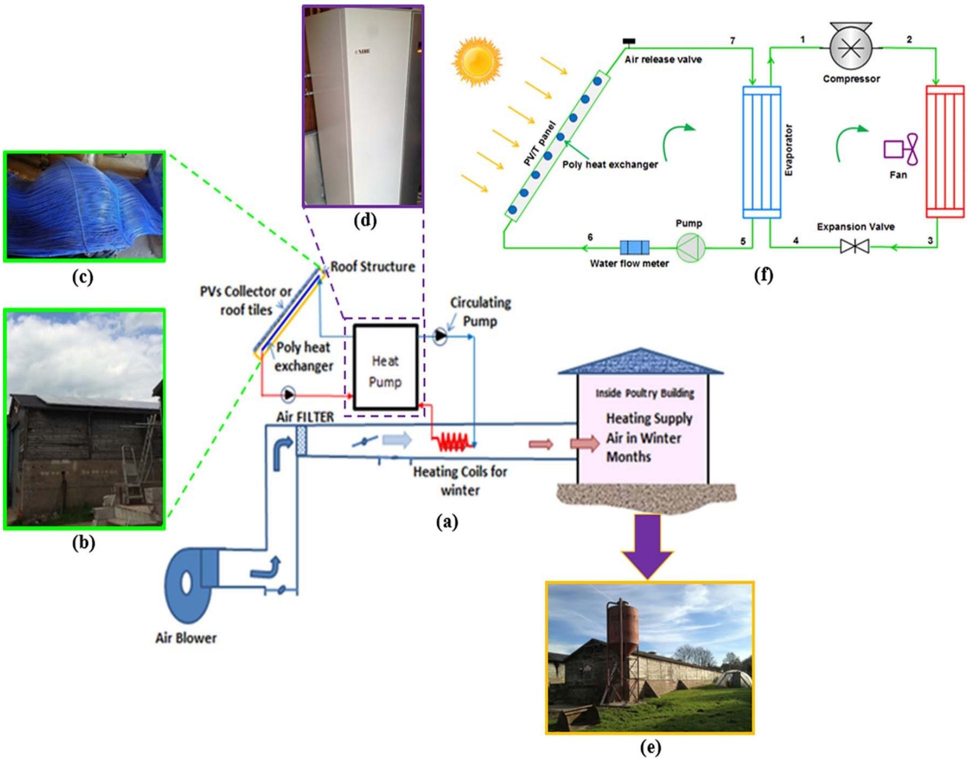


Figure II.17. (a) The schematic diagram of the hybrid PV/T with HP unit; (b) PV/T module; (c) PHE module; (d) NIBE HP system; (e) poultry shed at JWL; (f) working principle of the whole system.[68]

have been applied to design and assess on heating the poultry houses by using the SHWS. Furthermore, in terms of SAHS, the transpired solar collector (TSC) technology is proposed in order to pre-heat ventilation air and warm for the poultry houses [69,70,71]. Owing to the high primary cost and relatively long payback time on SHWS, many farmers squint towards to take a wait-and-watch method. The inexpensive expense TSC may be advocated for farmers who are more interested in reducing the operating cost

II.5.4.1Flat plate solar collector:

Flat plate solar thermal collector technology is commonly employed for heating water and providing space heating in poultry houses. These systems typically consist of a flat plate absorber and a transparent cover that allows solar radiation to pass through while minimizing heat loss. Glazed flat plate heating systems are particularly popular in poultry houses, maintaining a brooding temperature between 30 and 35°C. A well-designed flat plate solar collector can achieve an efficiency of 40–60%, converting approximately half of the incident radiation into usable heat. The installation of flat plate collector systems at chicken farms primarily aims to reduce heating loads rather than being a definitive solution. Despite the initial capital investment, this technology remains attractive for several applications due to its well-established methodology and low energy consumption. For example, Mirzaee-Ghaleh et al. [72] Mirzaee-Ghaleh et al. introduced an innovative hybrid solar hot water system (SHWS) with an auxiliary heater unit. This system functions with two heat sources: solar energy for the SHWS and fossil fuel for the auxiliary heater. In evaluating the system's performance during the heating season in poultry houses, the energy balance equation is provided by [72]:

$$mc_p \frac{dTi}{dt} = Q_{sup} + Q_s - Q_v - Q_w - Q_f \bigcup_{i=1}^{n} Xi,$$

The equation is defined as follows:

− \(T_i \) *indicates the indoor temperature* (°C),
− \(t \) *represents time* (s),
− \(Q_{sup} \) *stands for supplemental heat capacity* (kW),
− \(Q_s \) *signifies the sensible heat produced by broilers* (kW),
− \(Q_v \) *denotes the heat losses by the ventilation system* (kW),
− \(Q_w \) *represents the heat losses from walls and roof* (kW), *and*
− \(Q_f \) *indicates the heat losses from the floor* (kW).

The sensible heat from chicken is written by [72]:

$$Q_s = Q_{chicken} \cdot [0.8 - 1.85 \times 10^{-7} \times (10 + T_i)^4] \qquad (2)$$

$$Q_{chicken} = 10 \cdot m_b^{0.75} [4 \times 10^{-5} \times (20 - T_i)^3 + 1], \qquad (3)$$

The equation can be rewritten as follows:

− ($Q_{chicken}$) *represents the total heat produced by the chickens* (kW),
− ($m_{b)}$*denotes the mass of the chicken body* (kg). *The heat losses from walls* (Q_w) , *floor* (Q_f) *and ventilation* (Qv) *are obtained as* [72]:

$$Q_w = \sum(UA) \cdot (T_i - T_0) \qquad (4)$$

$$Q_f = F \cdot P \cdot (T_i - T_0) \qquad (5)$$

$$Q_v = c_p \cdot \rho \cdot V(T_i - T_0), \qquad (6)$$

The equation can be restated as follows:

− \(T_0 \) *represents the outdoor temperature* (°C),

− \(A \) *denotes the wall area* (m^2),

− \(P \) *stands for the perimeter of the house* (m),

− \(F \) *is a constant factor ranging between* 1.4 *and* 1.6, *and*

The useful heat energy from solar flat collector is given as [72]:

$$Q_u = A_C \cdot F_R \cdot \left[I_R \cdot (\tau\alpha) - U_L\left(T_{fi} - T_{at}\right)\right], \qquad (7)$$

The equation can be rephrased as follows:

− \(Q_u \) *represents the collected energy* (kW),

− \(A_C \) *denotes the collector area* (m^2),

− \(F_R\) *signifies the collector heat coefficient at the temperature* \(T_{fi} \),

− \(τ \) *indicates the solar transmittance,*

− \(α \) *represents the solar absorptance,*

− \(T_{fi} \) *is the inlet water temperature* ($°C$), *and*

− \(T_{at}\) *represents the environmental temperature* ($°C$).

$$Q_{AUX} = q_{sup} - Q_u, \qquad (8)$$

The equation can be restated as follows:

− \(Q_{AUX}\) *represents the capacity of the auxiliary heater* (kW).

The results demonstrated that this proposed system is capable of supplying a minimum of 20% of the necessary energy during winter and achieving significant energy savings of approximately 70%, which is noteworthy.

In another case, Reece [73] developed a solar thermal flat plate system to fulfil the heating requirements for broiler chickens in a typical brooding house. This system considers a combination of water- and air-type solar heat collectors. In daytime, air heated by air-type collectors passed through polyvinyl ducts and vents into the brooding shed, providing direct ventilation and heat to the chicks. This combination unit is able to supply all of the heat required each day and store enough energy to meet the heat demands each night under normal midwinter conditions. The water and air flat plate solar thermal collectors with a surface area are of 8.4 m2 as well as of 13.4 m2 for each 1000 birds, respectively. Results found that the system is more efficient than the most of the thermal collectors on the market and the energy saving of ~80% can be achieved in the heating season

II.5.4.2. Parabolic concentrated solar collector:

Due to the limited energy conversion efficiencies of conventional flat plate solar thermal collectors, larger parabolic concentrated solar collectors are often required to meet the heating demands of poultry houses. In contrast to traditional photovoltaic (PV) panels, parabolic concentrated solar technology harnesses solar radiation to generate electricity through the utilization of a steam turbine rather than the PV effect. Typically, mirrors or lenses are employed in concentrated solar thermal collector systems to capture and concentrate solar radiation onto a smaller receiving surface. Electrical energy is produced as the concentrated light is converted into heat, driving a steam turbine connected to an electrical generator. For example, Fawaza et al. [74] developed an innovative parabolic concentrator solar thermal unit utilization for a real chicken farm, which is 16 pens, each of 8.9 m^2 area with 100 broilers, located at the east of Lebanon. The system consists of a thermal storage tank with heat exchanger, a parabolic solar concentrator unit, an auxiliary heater system and two circulating pumps as depicted in Figure 3.

pumps as depicted in Figure 3. The merits of this system are that it requires a minor roof region and maintains longer time of superior energy. Moreover, it is found that the system is more efficient than the other solar collectors even though the capital cost is comparatively higher. Furthermore, this system also yields higher water temperature for heat stored usage in the heating season. To investigate the solar side loop of the unit, the transient performances of the working fluid within both the solar collector and storage tank are analysed through the energy balance equations.[68]

The useful heat gains for the water within the solar collector are given by [74]:

$$Q_u = F_R A_a\left[I_C - \frac{A_r}{A_a}U_V\left(T_{af,in} - T_a\right)\right], \qquad (9)$$

$-$ \(A_a\) *represents the aperture area of the collector* (m^2),

$-$ \(F_R \) *denotes the heat removal factor,*

$-$ \(A_r \) *signifies the receiver area of the concentrator* (m^2),

$-$\ ($T_{af,in}$\) *indicates the temperature of the antifreeze solution entering the collector* (°C)

$-$ \(T_a \) *represents the ambient air temperature* (°C).

The storage tank is given by [74]:

$$\left(\rho c_p V\right)\frac{dT_s}{dt} = Q_u - Q_l - (UA)(T_s - T_a), \qquad (10)$$

The equation is expressed as follows, where:

$-$ \(V \) *represents the volume of the water tank* (m^3),
$-$ \(Q_l\) *denotes the heat load removed from the tank* (kW),
$-$\ (Q_u\) *indicates the corrected effective useful heat gain for the heat exchanger effectiveness* (kW), *and*
$-$ \(T_s\) *signifies the temperature of water inside the tank* (°C).

The useful heat energy from the solar concentrator is obtained as [74]:

$$Q_u = m_{af}C_{paf}\left[T_{af,out} - T_{af,in}\right] \qquad (11)$$

The equation is as follows:

$-$\ ($T_{af,out}$\) *indicates the temperature of the antifreeze solution leaving the collector* (°C).

The heating exchanger entering temperature is written as [74] :

$$T_{w,in} = \frac{Q_u}{\eta \times m_{af}} + T_{af,in}\,, \qquad (12)$$

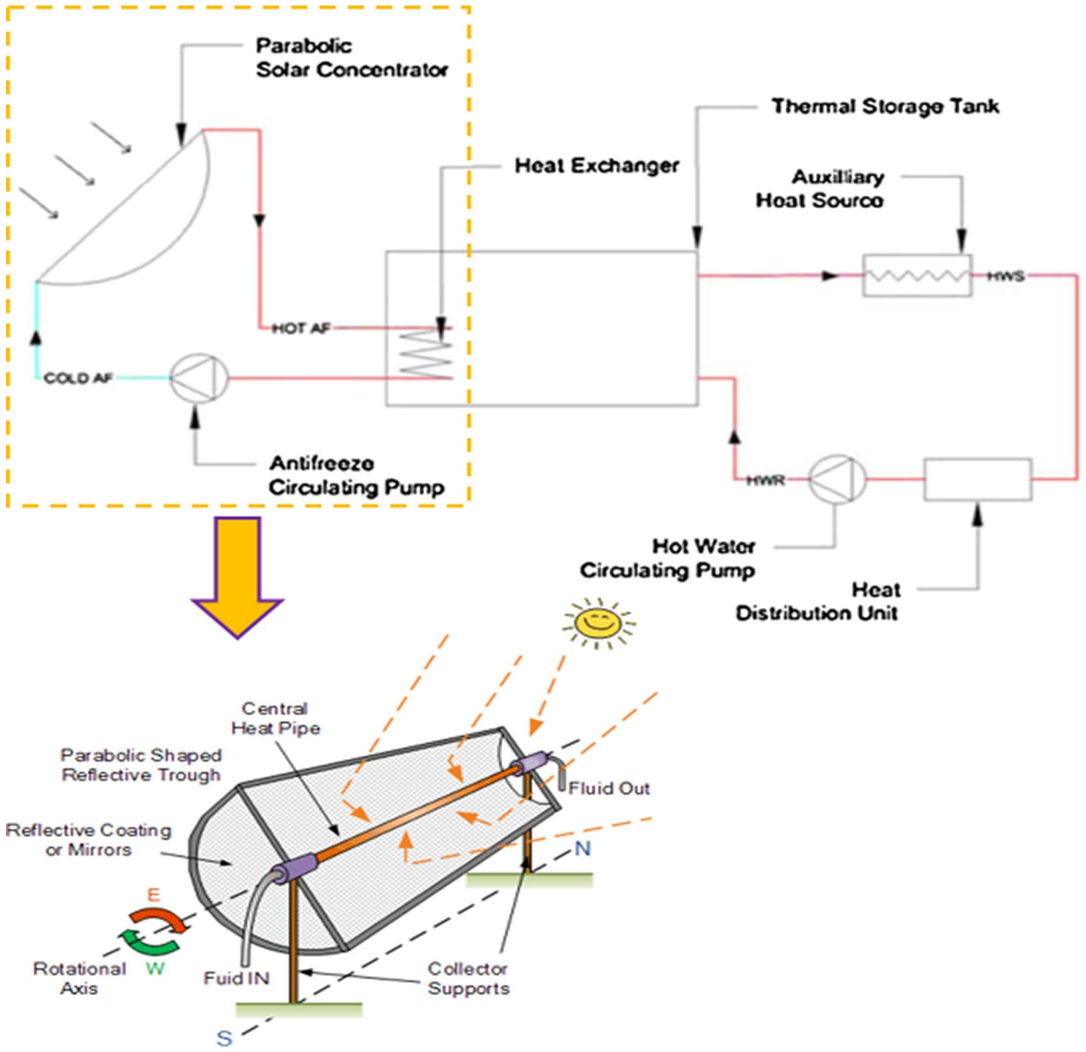


Figure II.18 The parabolic concentrator solar thermal unit used in the poultry house in Lebanon [75, 74].

The equation can be rephrased as follows:

- \(η \) represents the efficiency of the heat exchanger (%).

The findings reveal that the proposed system can meet 84% of the heating load for the entire growth cycle, resulting in energy savings of 74% throughout the entire operational period. Additionally, annual operating expenses and savings amount to approximately £2554, with a payback period of less than 5 years.[74]

II.5.4.3. Evacuated tubes solar collector

Evacuated tube solar thermal collector, which has a heat pipe being around through a glass tube under a vacuum, is widely used

for poultry houses as presented in Figure 4 Compared with the flat plate thermal collector, evacuated tube solar thermal collectorcan generate more heat energy by using vacuum tubes, which warm up solar absorber.

Chen and Sheng [76] presented a commercial evacuated tube solar thermal collector system with high efficiency to maintain the desired temperature for chicks and reduce the bill of costsin Taiwan. The system is driven by 1.6 m^2 of 18 vacuum tubes integrated into a novel poultry heater with a fin plate. The resultsdemonstrate that the evacuated tubes solar thermal collectorsystem has a good absorptive effect reaching 83%. Meanwhile, the system performance can achieve 51.5% or higher, resulting in a reduction of 148.6 kg of CO_2 emissions for 1000 chicks, and the novel poultry heater contributes to providing a constant temperature to keep chicks warm inside the shed.[68]

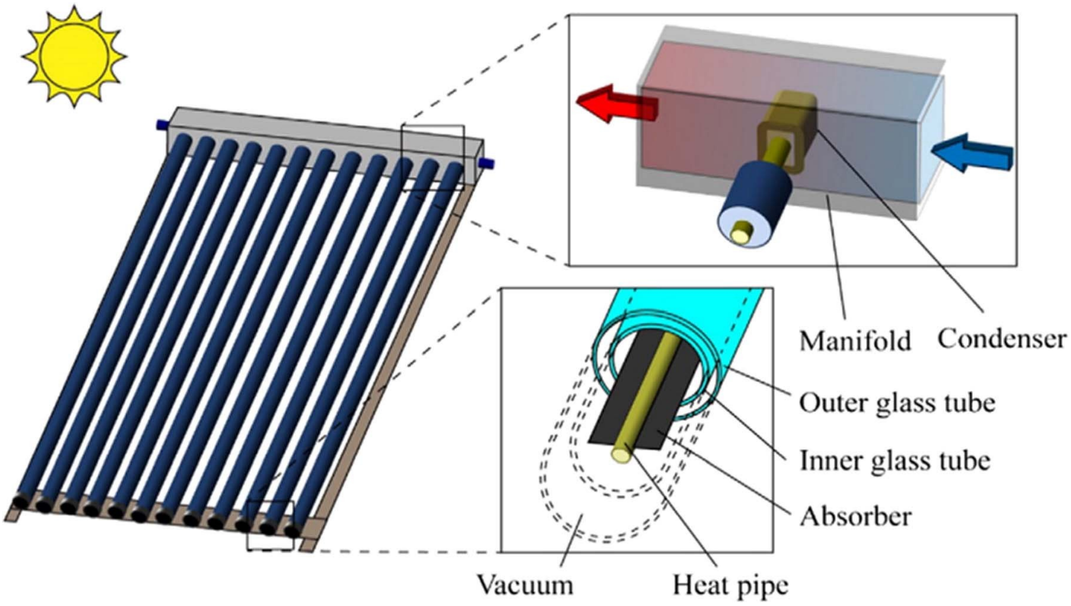


Figure II.19. The schematic diagram of evacuated tubes solar thermal collector [77].

II.6. Conclusion:

In conclusion, maintaining optimal heating conditions in poultry houses is fundamental to the overall well-being and growth of the birds. By understanding the unique requirements of chicks and chickens at different stages of development, farmers can implement effective heating systems and ventilation strategies to ensure a comfortable and conducive environment. Proper temperature regulation, coupled with efficient control systems, not only supports the physiological needs of the birds but also contributes to their health, productivity, and ultimately, the success of poultry farming operations. By prioritizing temperature management and environmental control, farmers can create conditions that foster thriving poultry populations and sustainable agricultural practices.

Chapter III

Experimental Approach

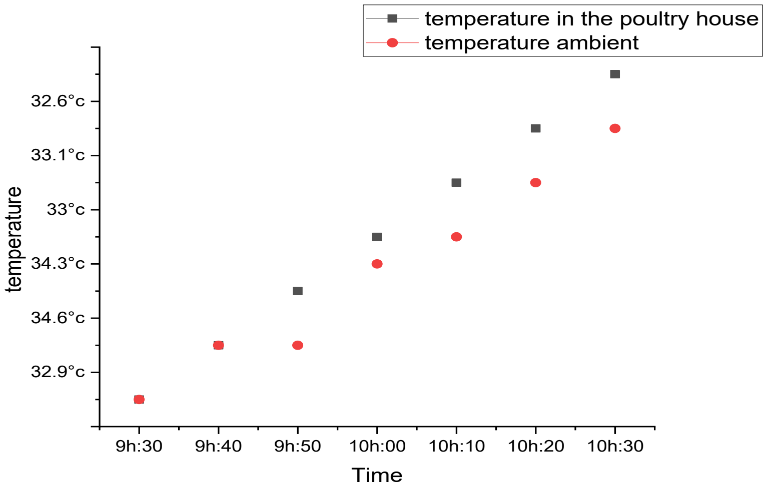


Table III.3: Measurement of the temperature - Using 3 pipes and 1 fan

Temperature Temps	P1	P2	P3	P4	P5	P6
10h:40	34.4°c	42.8°c	59.9°c	57.6°c	38.9°c	38.7°c
10h:45	35.1°c	40.4°c	57.4°c	57.3°c	39.6°c	39.3°c
10h:50	35.6°c	38.3°c	55.7°c	56.5°c	40°c	39.8°c
10h:55	36°c	40°c	53°c	55.9°c	40.2°c	40.5°c
11h:00	35.1°c	40°c	57°c	58.2°c	40.6°c	40.6°c
11h:05	35.2°c	38.7°c	57.4°c	58.6°c	40.8°c	40.8°c
11h:10	36.1°c	38.1°c	58.4°c	58.7°c	40.9°c	40.9°c
11h:15	37.1°c	38.1°c	55.7°c	56.3°c	40.7°c	41.1°c
11h:20	35.9°c	39.2°c	52.6°c	57.9°c	41.2°c	41.2°c
11h:25	36.1°c	38.3°c	53.1°c	57.4°c	41.4°c	41.3°c
11h:30	37.1°c	38.4°c	52.6°c	54.3°c	41.7°c	41.6°c
11h:35	37.1°c	38.3°c	52.4°c	59.6°c	41.5°c	41.4°c
11h:40	36.4°c	38°c	57.1°c	60.9°c	41°c	41.8°c

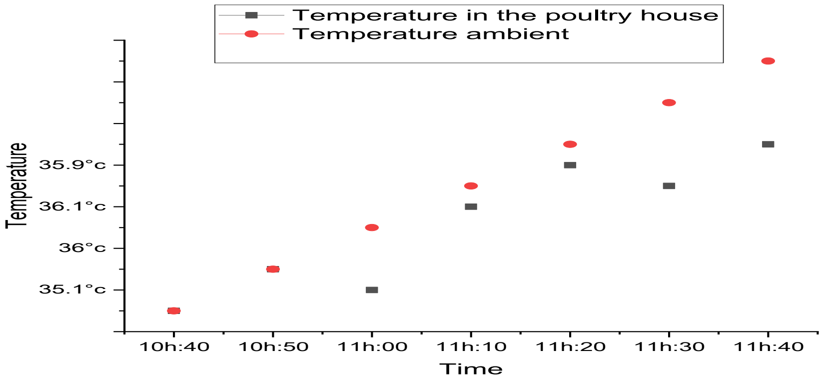


Table III.4: Measurement of the temperature - Using 6 pipes and 1 fan

Temperature Time	P1	P2	P3	P4	P5	P6
11h:55	38°c	4.8°c	51.2°c	49.8°c	42.1°c	43.1°c
12h:00	37.5°c	39.2°c	49.8°c	51.8°c	42.6°c	43.5°c
12h:05	38.7°c	38.5°c	48.3°c	49.7°c	42.9°c	43.4°c
12h:10	35.5°c	36.1°c	49.3°c	49.1°c	42.8°c	43.4°c
12h:15	37.8°c	36.5°c	51.3°c	48.9°c	42.7°c	43.2°c
12h:20	36.4°c	37.1°c	48.5°c	48°c	42.8°c	43.5°c
12h:25	35.2°c	38.8°c	47.2°c	51.2°c	42.6°c	43.4°c
12h:30	39.4°c	37.8°c	47.1°c	48.7°c	43.1°c	43.9°c
12h:35	38.3°c	37.3°c	46.4°c	49°c	43.2°c	43.9°c
12h:40	36.4°c	39°c	48°c	45.5°c	43.6°c	43.9°c
12h:45	36.2°c	37.7°c	45.4°c	49.1°c	43.4°c	44°c
12h:50	36.5°c	39.3°c	48.4°c	48.5°c	43.6°c	44.1°c
12h:55	37.1°c	38.5°c	46.5°c	48.9°c	43.7°c	44.2°c

Table III.5: Measurement of the temperature - Using 6 pipes and 2 fans

Temperature Time	P1	P2	P3	P4	P5	P6
13h:05	36.3°c	42.3°c	50.7°c	50.3°c	44.1°c	44.3°c
13h:10	36.9°c	41.2°c	52.5°c	50.1°c	44.9°c	45.4°c
13h:15	36.3°c	39.5°c	50.6°c	50.3°c	44.8°c	45.1°c
13h:20	36.3°c	38.4°c	47.9°c	49.2°c	44.6°c	45°c
13h:25	35.5°c	38.6°c	46.3°c	48°c	44.9°c	45.1°c
13h:30	37.7°c	38.7°c	47.5°c	49.2°c	44.8°c	45.1°c
13h:35	35.9°c	38.1°c	44.3°c	49.5°c	44.8°c	45.3°c
13h:40	35.4°c	38.8°c	47.5°c	47.5°c	44.5°c	45°c
13h:45	35.2°c	35.4°c	48°c	48.7°c	44.9°c	45.2°c
13h:50	35.4°c	38.6°c	45.5°c	47.8°c	45.1°c	45.2°c
13h:55	35.2°c	37.9°c	46.9°c	50.6°c	44.4°c	44.7°c
14h:00	36°c	38.2°c	46.1°c	47.1°c	44.8°c	45°c
14h:05	37°c	38.8°c	45.3°c	47.9°c	45°c	45.4°c

General conclusion

In conclusion, the study of the solar heating system for poultry barns has demonstrated that the proposed system effectively provides a suitable environment for poultry farming by enhancing barn temperatures through sustainable and efficient methods. The design, which incorporates glass and iron panels to absorb sunlight and heat the air inside the barn, has achieved an optimal thermal balance conducive to the health and comfort of the poultry.

Experiments conducted across four different scenarios reveal that the use of iron and glass panels significantly enhances air heating efficiency, particularly when paired with improved air distribution through fans. The findings underscore the viability of solar energy as a clean and sustainable source for barn heating systems. Moreover, the use of local materials such as iron and glass has proven to be effective in designing economical and environmentally friendly heating solutions.

This study recommends further research to explore optimal system configurations, including the appropriate number of pipes and fans, and to enhance thermal insulation techniques to minimize heat loss. Additionally, investigating alternative methods to increase solar heat absorption could further improve the heating system's performance. Ultimately, this research is expected to open new avenues for advancements in solar heating technology, thereby enhancing the sustainability of poultry farming and significantly improving its environmental and health standards.

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