People`s Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research

University of Echahid Hamma Lakhdar - El Oued

Faculty of Technology

Department of Mechanical Engineering

Dissertation

ACADEMIC MASTER

Domain: Science and Technology

Division: Mechanical Engineering

Specialty: Energy

Presented by:

- DEROUCHE INTISSAR
- AMMARI RAWANE

Entitled:

Experimental Investigation of Poultry House Heating System Enhanced with Heat Storage system

Dissertation Submitted in Partial Fulfillment of the Requirements for the Master Degree in energy

Publicly defended in: 28/05 /2025

Board of Examiners:

Pr. ATIA Abdelmalek	**Chairman**
Dr. MENECEUR Noureddine	**Supervisor**
Dr. ZEBIRI Oussama	**Examiner**

Academic Year: 2024/2025


بسم الله الرحمن الرحيم

شكر وعرفان

أتقدم بجزيل الشكر والعرفان إلى كلية علوم وتكنولوجيا بكافة كوادرها الإدارية والأكاديمية، التي وفرت لنا بيئة تعليمية مميزة ومحفزة على الإبداع والتميز.

كما أتوجه بخالص الشكر والتقدير إلى أساتذة قسم الهندسة الميكانيكية الأفاضل، كل باسمه ولقبه. فلقد كانوا لنا خير موجه ومعلم، أضاءوا لنا دروب العلم والمعرفة، ولم يبخلوا علينا بالدعم والنصح .والإرشاد طوال مسيرتنا الدراسية. لجهودكم القيمة في صقل مهاراتنا وتعميق فهمنا، نتقدم بخالص الامتنان والتقدير

الحمد لله الذي بنعمته تتم الصالحات واشكره عل توفيقه و هدايته في كل خطوة خطوتها في هذا العمل

إهداء

"وآخِر دَعْوَاهم أَنِ الحَمْد لِلهِ رَبِّ العَالَمِينَ"

الحمد لله عند البدء و عند الختام من قال أنا لها نالها

إله لا يطيب الليل إلا بشكره ولا يطيب النهار إلا بطاعته ولا تطيب اللحظات إلا بذكره الله جل جلاله انتهت الرحلة. لم تكن الرحلة قصيرة ولم تكن سهلة ولم يكن الحلم قريبا ومهما طالت فستمضي بحلوها ومرها

وفي اللحظة أكثر فخرا اهدي عملي هذا الى من رباني وكافح من أجلي الى المصباح الذي انار دربي ولمن أحمل اسمه بكل افتخار طاب بك العمر يا سيد الرجال وطبت لي عمرا أرجو من الله ان يمد في عمرك لترى ثمارا قد حان قطفها .. ابي العزيز

الى ملاكي في الحياة ومعنى الحب وقرة عيني واعز ما أملك الى بسمة الحياة وسر الوجود الى من كان دعائها سر نجاحي وحنانها بلسم جراحي الى غاليتي وجنة قلبي التي رافقتني وأرشدتني في كل مشاوير حياتي .. امي الغالية حفظها الله

إلى أخواتي انيس وملاك وادم سندي في الحياة ها أدامكم الله ضلعا ثابتا لي

إلى عزيزي مهدي ، الذي كان داعماً وسنداً حقيقياً لي في كل خطوة، فله كل الشكر على صبره وتشجيعه و إلى كل أصدقائي بدون استثناء

أتوجه بالشكر والامتنان الصادقين إلى زميلتي في العمل انتصار. لقد كنتي خير رفيق في هذه المسيرة الدراسية

أقدم خالص الامتنان والتقدير لأساتذتي المشرفين الكرام على مذكرة تخرجي، "منصر نور الدين وبوعزيز عماد الدين ." لقد كان لدعمهم العلمي الثمين، وتوجيهاتهم السديدة، وخبرتهم التي لا تقدر بثمن، الأثر الأكبر في إثراء هذا العمل البحثيإثراء هذا العمل البحثي.

والحمد لله على حسن التمام والختام.

عماري روان

بسم الله الرحمن الرحيم

"ربِّ اشرح لي صدري ويسر لي أمري واحلل عقدة من لساني يفقهوا قولي"

إهداء

في لحظات تكلل مسيرتي الدراسية بالنجاح والتفوق، أتقدم بخالص الشكر والتقدير إلى من كانوا لي السند والعون، وإلى من غمروني بحبهم .ودعائهم

إلى نفسي أو الً،

.التي خاضت غمار التحديات، وسهرت الليالي، وطمحت للعلا. أهدي هذا العمل إليكِ، سائلة الله أن يكون بداية لمزيد من العلم والنجاح ".اللهم انفعنا بما علمتنا، وعلمنا ما ينفعنا، وزدنا علمًا"

إلى من سهروا الليالي من أجلي،

:إلى نبع الحب والعطاء اللامحدود، اللذين لم يدخرا جهدًا في سبيل تعليمي وتقدمي، وأخص بالذكر

- **والدي الحبيب** :يا من كنت لي القدوة الحسنة، ومنبع الحكمة، ويا سندي في دروب الحياة. كلمات الشكر تعجز عن وصف فضلك وتضحياتك التي مهدت لي طريق العلم.
- **والدتي الغالية** :يا سيدة الفضل والكرم، ويا منارتي التي أنارت دربي بالدعاء والحب، كنتِ وما زلتِ نعم السند والعون لي في كل خطوة. لكِ مني كل الحب والامتنان.

إلى رفاق الدرب،

.إلى إخوتي الأعزاء، عادل ورائد، وأخواتي أحلام وأمنية الشفاء، كنتم لي نعم السند والعون، وبوجودكم ودعمكم ازدانت دروب العلم والمعرفة وفي هذا المقام، لا يسعني إلا أن أتذكر أختي الغالية التي رحلت عنا بجسدها، لكن ذكراها الطيبة وروحها الطاهرة تظل حاضرة في قلوبنا. أسأل
.الله لها الرحمة والمغفرة وأن يسكنها فسيح جناته

إلى أساتذتي الأفاضل،

أعرب عن خالص شكري وتقديري إلى مشرفي الفاضل **الدكتور منصر نور الدين،** الذي أضاء بتوجيهاته ونصائحه القيمة، وكان له الفضل .الكبير في إثراء هذا العمل

.وإلى الأستاذ القدير **بو عزيز عماد الدين،** الذي لم يبخل علينا بوقته وجهده، فله مني جزيل الشكر والامتنان

إلى كل من كان عونا لي،

وإلى عزيزي **يوسف،** الذي كان خير سند وداعم لي في كل خطوة، ألهمتني مثابرته، وشجعني حضوره. فله مني كل الشكر والامتنان على صبره .وتشجيعه

.وإلى زميلتي في العمل **روان،** على تعاونها ودعمها المستمر

أسأل الله التوفيق والسداد في خطواتي القادمة، وأن يجعل هذا العمل خالصًا لوجهه الكريم ونافعًا للجميع، وأن يرزقنا المزيد من العلم والعمل .الصالح

"ربنا لا تزغ قلوبنا بعد إذ هديتنا وهب لنا من لدنك رحمة إنك أنت الوهاب"

درويش انتصار

Abstract

This thesis presents an experimental study of a heating prototype for poultry houses in the arid regions of Algeria, specifically in El Oued. A custom-designed solar thermal collector is installed on the poultry house roof. The model features insulated sandwich panel walls and a wooden-framed heating unit mounted on the roof. The heating system includes a primary layer of black-painted iron plates to maximize solar absorption. A phase change material (PCM) is placed on this layer to store thermal energy, allowing the poultry house to remain heated during non-sunny hours. This assembly is covered by a secondary layer of glass plates functioning as a flat-plate solar collector.

The system design enables air intake from one side, circulation beneath the iron plates, and outlet through ducts on the opposite side. The airflow beneath the solar collector, combined with the PCM, delivers warm air into the poultry house. A ventilation system assists in evacuating air to the outside. Measurements were taken starting at 8 a.m. The results were compared to a system without PCM and were thoroughly analyzed and discussed. This method enhances productivity and reduces energy costs.

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

Résumé

Ce mémoire présente une étude expérimentale sur un prototype de chauffage pour un poulailler situé dans les régions arides d'Algérie, plus précisément à El Oued. Un capteur solaire thermique spécialement conçu est installé sur le toit du poulailler. Le modèle comprend des murs en panneaux sandwich isolants et un dispositif de chauffage à structure en bois monté sur le toit. Ce système intègre une première couche de plaques de fer peintes en noir pour maximiser l'absorption solaire. Sur cette couche, un matériau à changement de phase (MCP) est installé pour stocker l'énergie thermique, permettant de chauffer le poulailler pendant les heures sans ensoleillement. L'ensemble est recouvert d'une deuxième couche composée de plaques de verre, agissant comme un capteur solaire plan.

La conception permet l'entrée de l'air d'un côté, sa circulation sous les plaques de fer, puis sa sortie par des conduits situés à l'opposé. Le flux d'air réchauffé sous le capteur solaire, combiné à l'effet du MCP, introduit de l'air chaud dans le poulailler. Un système de ventilation évacue ensuite l'air vers l'extérieur. Les mesures ont été réalisées à partir de 8 heures du matin. Les résultats, comparés au système sans MCP, ont été analysés et discutés. Cette approche contribue à améliorer la production tout en réduisant les coûts énergétiques.

Mots clés : capteur thermique, volaille, chauffage, efficacité énergétique.

الملخص

يقدّم هذا البحث دراسة تجريبية لنموذج أولي لنظام تدفئة مخصص لحظيرة الدواجن في المناطق الجافة من الجزائر، وتحديدًا في منطقة الوادي. تم تركيب مجمّع شمسي حراري مصمم خصيصًا على سطح الحظيرة. يتكوّن النموذج من جدران مصنوعة من ألواح عازلة (ساندويتش)، بالإضافة إلى وحدة تسخين بهيكل خشبي مثبتة على السطح.

يتضمن نظام التسخين طبقة أولى من صفائح الحديد المطلية باللون الأسود لتعزيز امتصاص الطاقة الشمسية. وقد تم تركيب مادة متغيرة الطور (PCM) فوق هذه الطبقة لتخزين الطاقة الحرارية، مما يتيح تسخين الحظيرة خلال ساعات غياب أشعة الشمس. وتغطي هذه التركيبة طبقة ثانية من الزجاج تعمل كمجمع شمسي مسطح.

يسمح التصميم بدخول الهواء من جانب واحد، ثم يتدفق تحت صفائح الحديد ويخرج من خلال قنوات في الجهة المقابلة. يُسهم تدفق الهواء المسخن تحت المجمّع، إلى جانب تأثير الـPCM ، في إدخال هواء دافئ إلى داخل الحظيرة، ويقوم نظام التهوية بطرد الهواء إلى الخارج. قمنا بعدة عمليات قياس من الساعة الثامنة صباحًا. وقد تمت مقارنة النتائج مع نظام لا يحتوي علىPCM ، وتم تحليل النتائج ومناقشتها. تؤكد النتائج أن هذا النظام يمكن أن يُحسّن من إنتاجية الحظيرة ويُقلّل من التكاليف الطاقوية.

الكلمات المفتاحية :مجمّع حراري، دواجن، تدفئة، كفاءة طاقوية.

Chapter I:Bibliographic studies

Chapter II: State of the art: Heating systems forpoultry.

ChapterIII :Experimental Approach

Table of Figures

List of Tables

Glossary of Terms

Term	Definition	Page Reference
Canopy	A covering or overhead structure that shields or influences heat distribution in an infrared heating system.	47
Emitter	A device that heats up and radiates heat, forming a core component of infrared heating systems.	-
Heat Exchanger	A device that transfers heat between two or more fluids, commonly used in thermal energy storage systems and various heat transfer applications.	-
Heat Recovery	A technology that improves system efficiency by capturing and reusing waste heat from exhaust gases or other processes.	31
Heat Storage System	A system designed to store thermal energy for later use, contributing to balancing energy production and consumption within Thermal Energy Storage (TES) technologies.	-
HVAC System (Heating, Ventilation, and Air Conditioning System)	A comprehensive system engineered to create a comfortable indoor climate, encompassing heating, ventilation, and cooling operations, often leading to significant energy savings.	-
Infrared Heating System	A heating system that directly transfers heat to objects and people using infrared radiation.	-
PCM - Phase Change Material	Materials that absorb and release substantial amounts of heat during their phase transition (e.g., from solid to liquid), commonly employed in thermal energy storage systems to enhance efficiency.	-
Stove	A heating appliance that emits heat through either radiation or convection, often integrated into various heating systems.	-
Temperature and Humidity Control Systems	Specialized systems designed to manage and maintain desired levels of temperature and humidity in indoor environments, often facing challenges due to the interplay between these two factors.	-
Thermal Energy Storage (TES)	The process of collecting and storing thermal energy for future use, aiming to stabilize energy resources and improve overall energy utilization efficiency.	-
Thermistor	A precise temperature-sensing device used to measure and control temperature, playing a crucial role in environmental regulation systems.	-

General Introduction

General introduction

The poultry industry has witnessed substantial growth globally, driven by increasing demand for affordable and high-quality animal protein. Maintaining optimal environmental conditions in poultry houses is essential to ensure the health, welfare, and productivity of the birds. Among the various factors influencing poultry performance, thermal management, especially heating during cold seasons, is a critical aspect.

Traditional heating methods for poultry houses predominantly rely on fossil fuels such as coal, wood, gas, and diesel. These systems, while widespread, present significant drawbacks including high energy consumption, operational costs, emission of harmful pollutants, and negative impacts on bird health. The growing environmental concerns and the push toward sustainable farming practices have sparked interest in innovative heating solutions that integrate renewable energy sources and advanced thermal storage technologies.

Phase Change Materials (PCMs) and other heat storage systems have emerged as promising technologies to improve heating efficiency in poultry farms by storing thermal energy and releasing it when needed, thereby reducing energy consumption and enhancing temperature stability. This research aims to experimentally investigate a poultry house heating system enhanced with thermal storage, focusing on the integration of PCMs to achieve improved energy efficiency and environmental sustainability.

The thesis is organized into three main chapters:

The first chapter presents a comprehensive review of previous research related to poultry house heating systems and thermal storage technologies. It explores various heating methods, the role of renewable energy, and the application of PCMs for thermal energy storage. The chapter highlights experimental and numerical studies that assess the performance of heating systems, focusing on energy savings and the maintenance of optimal environmental conditions for poultry.

The second chapter provides a detailed overview of existing heating technologies employed in poultry farming. It covers traditional heating systems, including solid fuel, gas, electric, and diesel-based heaters, along with their advantages and limitations. Modern heating systems based on renewable energy sources such as solar, biomass, geothermal, and infrared technologies are also discussed. Furthermore, this chapter addresses the importance of heat storage systems and control strategies to improve energy efficiency and reduce environmental impact.

The third chapter describes the experimental setup, materials, and methods used to evaluate the proposed poultry house heating system enhanced with a phase change material-based thermal storage unit. It includes the design of the system, measurement techniques, and data analysis procedures. The results section presents findings on the system’s thermal performance, energy consumption, and impact on indoor environmental conditions. Finally, conclusions are drawn regarding the effectiveness of the integrated heating and storage system and recommendations for future work are provided.

In summary, this study identified best practices for implementing efficient and sustainable heating systems in poultry houses and provided actionable recommendations to enhance performance while minimizing environmental impact. This structured approach facilitates a comprehensive understanding of both the theoretical foundations and practical applications of advanced heating solutions in poultry farming, ultimately contributing to the development of sustainable and efficient poultry production systems. Finally, the work concludes with a general summary that highlights the key findings and outlines potential directions for future research.

Chapter I

Bibliographic studies

I.1. Introduction

Given the significant growth witnessed by the poultry industry, there is a need to explore innovative and sustainable solutions to enhance productivity while reducing costs. Heating systems in poultry houses are critical factors affecting both the safety and productivity of poultry, especially in areas with cold or variable climates. This study aims to investigate and evaluate the performance of a poultry house heating system that incorporates a thermal storage solution, with a focus on incorporating phase change materials (PCM) and advanced thermal storage technologies. Our research is based on a comprehensive analysis of previous studies that have explored different elements of heating and thermal storage systems within poultry farms. These studies include experimental investigations and mathematical models designed to improve the efficiency of heating systems and reduce energy consumption. Through this research, we aim to provide valuable insights into the development of heating mechanisms in poultry houses using advanced thermal technologies.

I.2. Brief history of heating devices

Solar photovoltaic systems for power generation in poultry houses play an important role in poultry production. Ernest F. Bazen and Matthew A. Brown [1] reviewed the advantages and limitations of these systems. Given the steady growth in recent years in the poultry industry in Tennessee, they sought to investigate the impact of alternative energy programs, grants, and other incentives on the feasibility of solar photovoltaic systems in several solar areas within the Tennessee poultry industry, in order to maintain the economic viability of poultry production in the state given the high costs of materials used in the production of solar photovoltaic panels, the economic viability of adopting solar photovoltaic energy for poultry producers was evaluated in each of the five Tennessee communities. Initial results showed that incentives above current levels prior to the adoption of solar photovoltaic systems would be financially beneficial.

Marcelo Bastos Cordeiro et al [2], conducted a study to evaluate the effect of different heating systems for poultry houses on the thermal comfort and animal performance of broiler chicks raised in the winter period in the southern region of Brazil. A randomized block design was used, with three heating systems. The heating systems evaluated were: wood-fired oven (indirect air heating); infrared gas bells; Infrared gas bells; and radiant heating drums with supplementary heating from gas-fired infrared bells, were used in three poultry houses with 17,700 birds (Cobb) per house to evaluate the thermal environment and animal performance. The results showed that the drum and bell system is the most efficient in maintaining the temperature and relative humidity of the air at a state of thermal comfort for the birds. Thus, it provides better weight gain, feed conversion and production efficiency.

E. Mirzaee-Ghaleh et al [3] , experiments were conducted in a typical poultry house with a length of 3-4 meters and an average height of 2.90 meters containing 100 broiler chickens (Cobb breed), with feeding and drinking water facilities as shown in Figure (1), aiming to monitor the indoor climate management and compare fuzzy logic and on/off controllers in a typical poultry house at the University of Tehran, Karaj, Iran , Three fuzzy logic controllers were developed and tested to maintain the internal parameters (temperature, humidity, CO_2 and NH_3) at the desired values using LabVIEW software. The results showed that the fuzzy controller provides better response for temperature and humidity. For fuzzy controller, the percent of working time in which temperature and relative humidity were maintained in less than ±1 C and ±5% from the set points were found to be 78.76% and 96.83%, respectively. These percentages for on/off controller were calculated as 31.36% and 68.35%. Results showed that the mean value of CO2 concentration with on/off controller (1124.64 ppm) was lower than that of fuzzy controller (2582 ppm). However, NH3 concentration was the same for both controllers. It was found that the maximum energy consumption was for heating the poultry house. The mean value of total power consumption by the actuators for fuzzy system was found to be 389.59 kJ/h which is 42% lower than that of on/off controller (664.49 kJ/h).

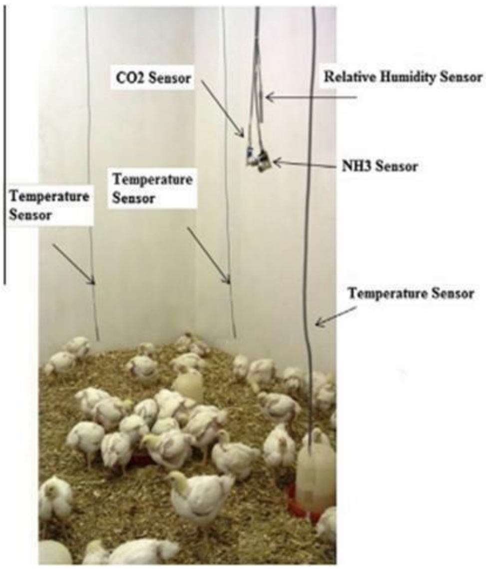


Fig. 1. Model poultry house uses for experiments. [3]

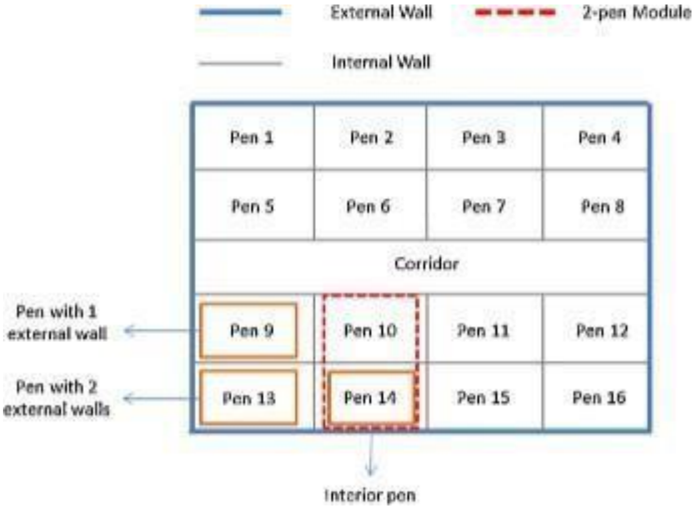


Fig.2. Floor plan for a 16-pen poultry house [4].

In the context of searching for permanent solutions for poultry farming, Fawaz et al. [4]. developed an innovative model for a local ventilation and heating system based on solar energy.

The researchers used a three-dimensional (CFD) model to analyze the efficiency and performance of the system. The results showed that high heating efficiency was achieved, which led to 75% energy savings compared to traditional systems. The thermal load was also reduced by 65% (Figure 2), as the system contributed to meeting heating needs using solar energy by 84%, which enhances environmental sustainability (Figure 3).

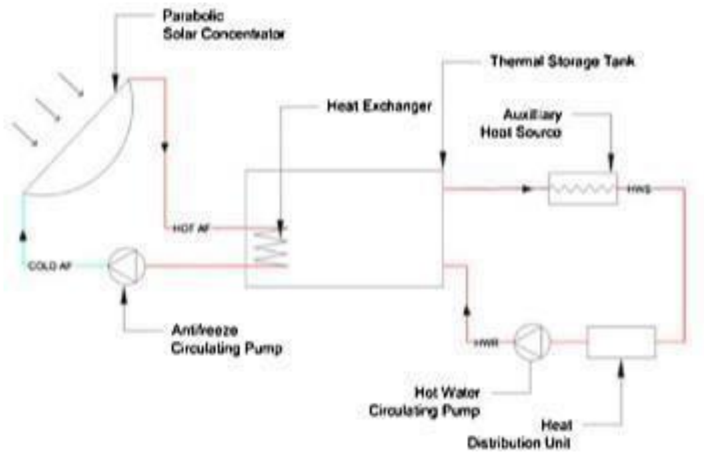


Fig. 3. Solar-assisted heating system [4].

In their study conducted, Kyeong-seok Kwon et al [5] , discussed the importance of controlling the airflow path through the vents to stimulate heat exchange in poultry houses especially during winter. They discussed the jet distance model to establish a cold jet path control and management plan proposed by Zhang and Strom (1999) (Figure 4) . However, they encountered difficulties in quantitative and qualitative assessments of the visible airflow and the specific number of vent openings, to address these limitations and difficulties, a computational fluid dynamics (CFD) simulation was performed to analyze the thermal distribution of the ventilation area by calculating the jet and droplet distance on a commercial chicken coop with multiple vents qualitatively and quantitatively, in Seoul, Republic of Korea. Their regression models were used to validate the accuracy of the developed method and compared it with the jet distance predictions using the experimental conditions used by Strom & Zhang (1999), the results showed that in the validation test, the regression model using the corrected Archimedes number more accurately predicted the jet-drop-distance in the simulation model (R^2 = 0.90). The validated method was subsequently applied to the analysis of the jet-drop- distance in a mechanically ventilated broiler house with multiple slot-openings. Trends of the CFD computed jet-drop distance were analyzed according to such variables as ventilation rate, initial angle of slot openings and outdoor air temperature.

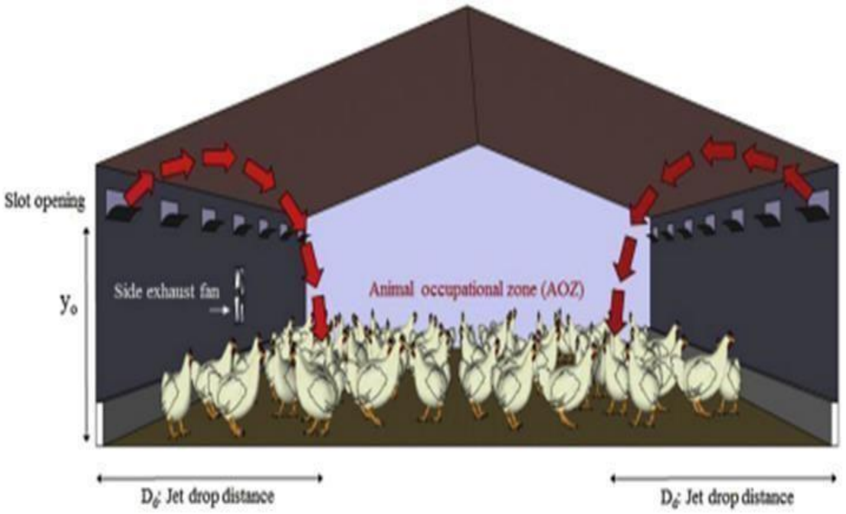


Fig. 4. Concept of the jet-drop-distance in a broiler house. [5]

G. Zhou, M. Pang [6], An experimental and simulation study was conducted on the thermal behavior of a collection wall system (Trump Wall) stored using PCM for a full day in Beijing (China), Zhou, Pang A collection and storage wall system was establish using PCM on the lower floor of a building where the environmental temperature changes little, insulated by a curtain installed between the glass and the wall that can be removed during the unloading process to reduce heat losses and also serves as a target for passive solar heating, With the addition of a solar radiation meter to measure the flow of radiant energy emitted by the lamps as shown in Figure (5,6) , the study was conducted during the day (6.5 hours of charging process) to increase thermal storage and during the night (17.5 hours of discharging process) to release heat into the room through air circulation. The results showed as follows: The temporary surface temperature of the gap side of the PCM board Tw, Ch first rises rapidly, then slowly then quickly again during the charging period; While in the unloading period tw,ch first decreases sharply and then decreases slightly for 15 hours, which indicates the release of heat in the form of latent heat for a long time, the temperature on the PCM panel surface ascends with the increasing of height but not evenly, and the top thermocouple which is near the outlet vent gives descending temperature due to the cooling effect from the surroundings, the gap air temperatures, glazing temperature and internal temperature are similar. Both air flow rate fluctuates the rate of heating by air circulation up and down during the charging period, and then shortly after the initial sharp declines, remains at values almost constant during the emptying period. The internal temperature was found to be higher than 22°C during the entire discharge period (17.5 hours) under the current circumstances, which indicates that indoor thermal comfort can be maintained for a long time by using PCM in the collector and storage wall system.

In order to provide ideal environmental conditions in poultry houses. Numerical modeling of heat and mass transfer processes. By Fernando Rojano et al [7]. Where CFD was used as a tool to analyze and predict the performance of heating and ventilation systems on the indoor climate and air quality in poultry houses, where the models showed good agreement between the predicted values and the experimental data of the indoor climate, with a low margin of error, the RMSE for temperature was recorded at 1.0 °C, and the RMSE for humidity at 0.26 g [H_2O] kg^{-1}.

The study noted that the distribution of heat and humidity was well homogeneous across the house, especially when using low temperatures and heating through the energy source - (Figure 7) The system can maintain heat during the night or during non-active times, which will contribute to saving energy and creating a better environment for the healthy growth of poultry.

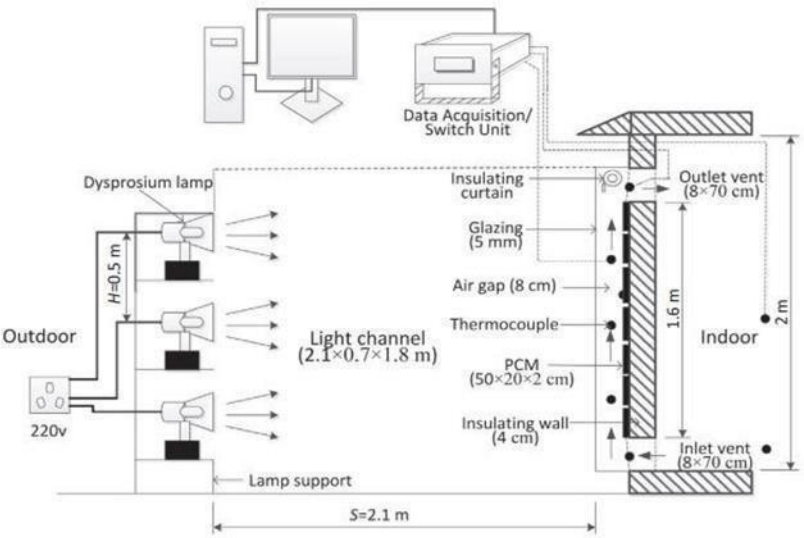


Fig. 5. Schematic sketch of the experimental setup. [6]

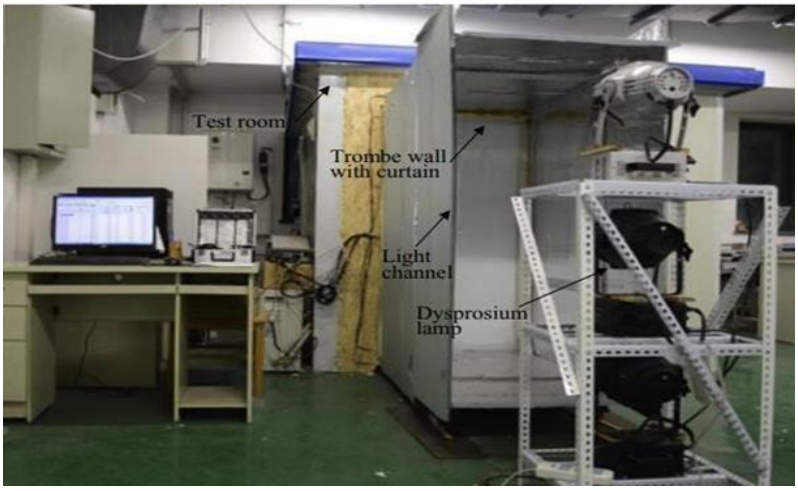


Fig. 6. The photo of the experimental system. [6]

A numerical model was conducted by Jacek Kapica et al. [8] where programs were used to analyze and evaluate the performance of Matlab/Simulink systems and calculate the heat requirements for up to 2400 birds. The study indicated that a larger system could lead to a reduction in CO_2 emissions (Figure 8). The calculations also showed that the effective use of thermal units could reduce heat consumption by 75%, where the reduction in emissions could range from 0.11- 0.22 kg per kg of bird mass. The researchers concluded that it is possible to benefit from renewable energy such as solar and wind energy in improving the sustainability of farms.

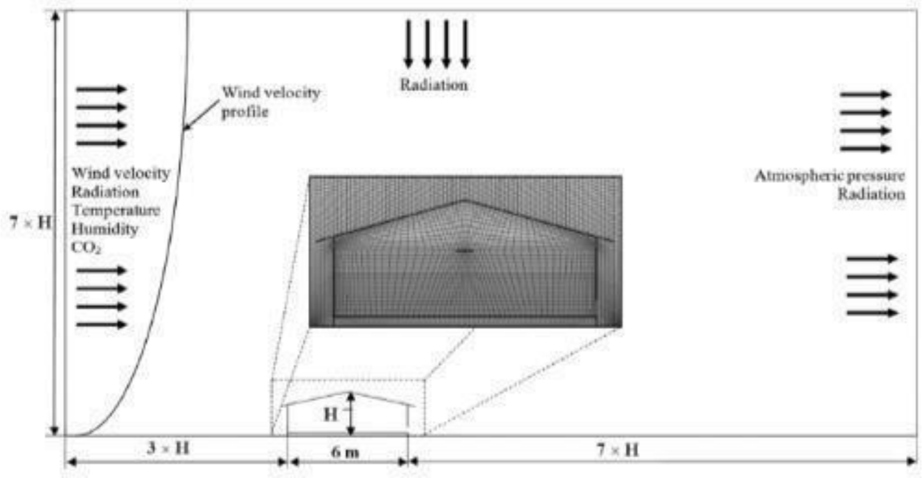


Fig.7. Boundary conditions of the domain studied [7].

Shaun Smith et al [9]. conducted a study of three multi-house broiler farms (Farms A, B, C) stocked with Ross 308 birds. Farm A consisted of four broiler sheds, each holding 35,000 birds. Three of the houses were equipped with direct gas heating systems and the fourth house was equipped with a “cobo” heating system. Farm B consisted of five broiler sheds, each holding 28,000 birds. Four of the houses were heated with direct gas heating systems system, and finally, Farm C consisted of three broiler houses, each with a capacity of 27,000 birds, two of which had direct gas heating systems while the third house was heated with a “wood pellet” stove (Solutions Energy Lee, USA). The farms were sampled during a year (June 2013 to June 2014) in Ireland as shown in Figure (9) .to compare the effect of three indirect heating systems on direct gas heaters on the population, results showed that indirect heating systems did not affect bird welfare, flock performance or Campylobacter.

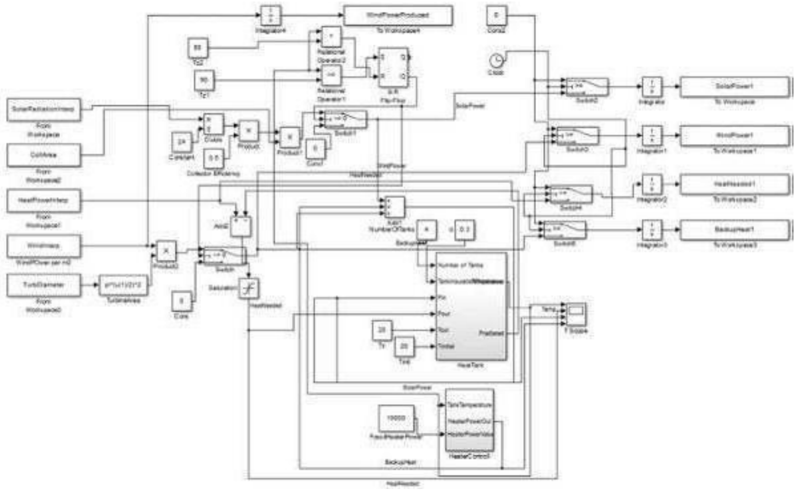


Fig. 8. Diagram of the Simulink model [8].

However, significant differences in litter quality, CO_2 concentrations and bird responses to stress associated with farm management practices have implications for optimal poultry production. Campylobacter disease was more likely to become established in broilers at later stages of flock life (≥22 days) than in young birds, regardless of heating system.

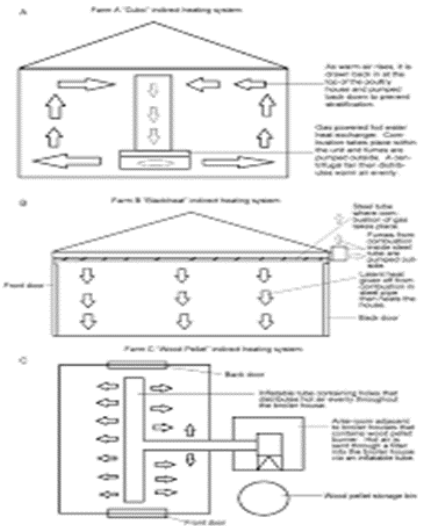


Fig. 9. Indirect heating system diagrams [9].

A. Costantino et al [10], a simulation model for estimating energy consumption for climate control in broiler houses was performed based on the simple hourly method adaptation of ISO 13790, to evaluate animal welfare for energy consumption for heating, cooling, ventilation and key indoor environmental parameters. The computational model, whose structure is based on five computational steps, was developed and its outputs were compared with a dataset obtained during a monitoring campaign in Italy, it was noted that the model proved to be reliable in terms of environmental criteria and energy consumption estimation. The scope for improvement lies in predicting relative humidity, taking into account the moisture storage characteristics of the envelope, ensuring the tuning of the evaporation pads modelling and enabling further improvements in the form of a more user-friendly interface and considering more aspects, for example, calculating the thermo-humidity velocity index (THVI), to estimate the heat stress conditions of birds on an hourly basis.

Mohamed S. Yousef and Hamdy Hassan [11], an experimental evaluation of the performance of the solar distillation system with a PCM storage unit was conducted in terms of energy, thermal energy and economy using two technologies: copper hollow pin fins embedded inside the PCM and the use of mesh wool fiber (SWF) in the basin of the solar distillation device with PCM. The study was carried out in four cases: the traditional distillation device, the distillation device with PCM, the distillation device with PCM and PF, and the distillation device with PCM and SWF, and compare them with each other, The distillation device was designed and built to examine the effect of integrating a PCM storage unit on the productivity of fresh water and thermal energy in solar distillation devices in Egypt, as shown in Figure (10,11) , which was carried out according to the following procedures: Before making any experimental measurements, during each time measurement and making sure that the correct measurements are taken, the amount of fresh water collected is carefully measured and recorded, repeating the previous two steps (3 and 4) at each time step, and finally the end. Full day's readings. It was noted that the total daily cumulative yield of fresh water for the distiller equipped with PF-PCM, which was estimated at

3.81 Kg/m^2 h, was greater than the traditional distiller, the distiller equipped with PCM-SWF, and the distiller equipped with PCM. As for enhancing productivity, the distiller equipped with PCM-SWF during the day was 14%, with productivity during the night decreasing by 14%. 80% compared to the PCM-based distillation device, The total daily thermal evaporative energy of the distiller equipped with SWF-PCM was greater than that of the conventional distiller, Distillation with PCM and Distillation with PF-PCM, The average energy efficiency of the distillation device equipped with PF-PCM technology was 37.5% , which is greater than the energy efficiency of other devices, With the PF-PCM the highest cumulative daily water productivity and energy efficiency were achieved, however, With SWF- PCM the highest energy efficiency is achieved.

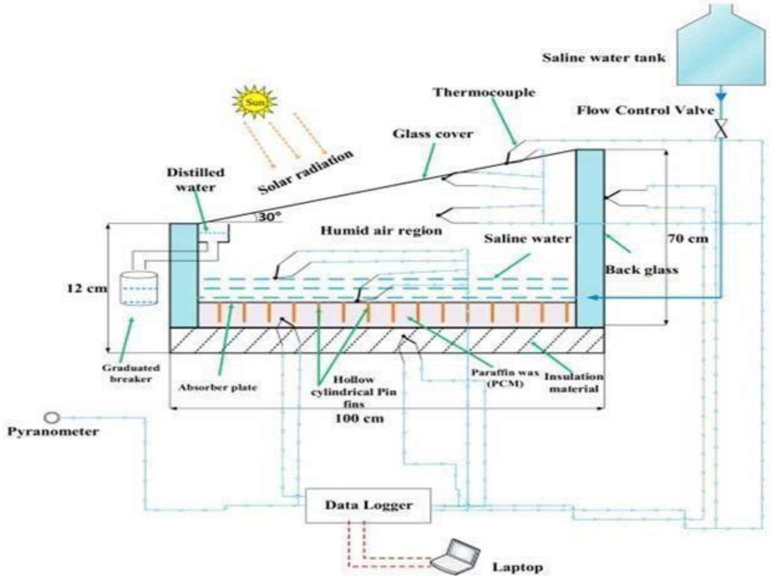


Fig. 10. Schematic diagram of the single type solar distillation with PCM-based pin fin heat sink [11].

Fig. 11. A photographic of the setup of the solar still with PCM and steel wool fibers [11].

In the effort of the effort, a numerical model was developed to analyze by Wei Chen Wei li. [12] The thermal performance of a composite wall was evaluated where it was integrated with phase change materials (PCM) (Figure 12). The results showed that this design contributes to increasing the thermal storage efficiency compared to conventional systems. It was found that the use of the composite wall leads to a temperature increase of 20.2%. The thermal efficiency of the wall was estimated at 76.2%. This indicates that a large proportion of the stored heat can be used for heating at night.

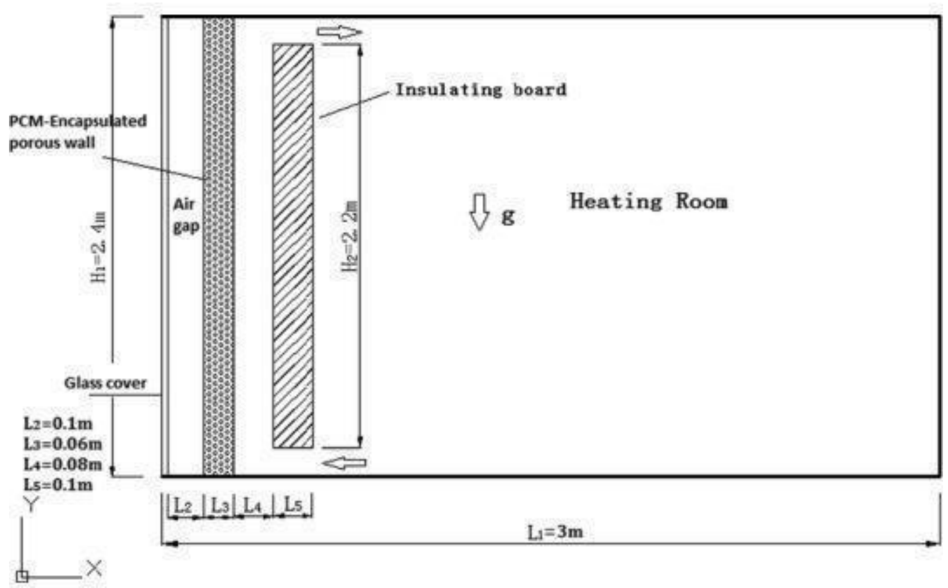


Fig. 12. Schematic of a passive solar composite wall with encapsulated PCM parti [12].

In addition to developing materials and heat transfer methods, Idris Al-Siyab and researchers also studied [13] the effect of design factors such as tilt angles on the performance of heat storage systems. An experiment was conducted to explore the dissolution characteristics of a thermal energy storage system using phase change materials (PCM) by creating a pilot set consisting of a circular thermal storage system. Paraffin wax was used as the phase change material, and a model was designed using COMSOL to study the effect of different tilt angles (0°, 45°, and 90°) on the performance of the system (Figure13). The results showed that the tilt angle has a significant effect on the temperature distribution in the storage system, as it was observed that the melting rate was higher at the tilt angle of 45° compared to the other two angles. This is due to the improved convection movement and uniform heat distribution. Numerical modeling also showed that the flow of liquid PCM inside the storage system was proportional, which affected the melting rate of the material. In addition, increasing the heat transfer fluid (HTF) flow rate from 60 mL/min to 120 mL/min did not significantly affect the melting time, but increasing the HTF temperature reduced the PCM temperature.

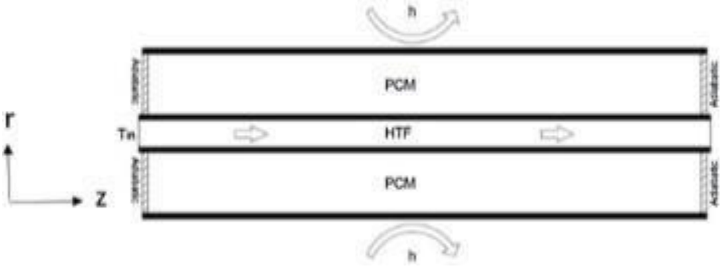


Fig.13. Schematic of model domain along with the boundary conditions [13].

Materials used in heat storage. The geometric design of the system plays an important role in improving heat transfer efficiency. Therefore, some studies have focused on developing innovative systems, such as the use of heat pipes, to improve thermal storage performance. Matteo Belardo and researchers [14] designed a new system that uses methanol-filled heat pipes to transfer heat from the absorber to the storage section. The system consists of a fully insulated aluminum structure (Figure 14) containing a phase change material called polyethylene glycol (PEG 6000) as the thermal storage medium (Figure 15). The system's performance was evaluated through numerical modeling and experiments under various climatic conditions. The results showed that the system can achieve a solar fraction of approximately 56% and produce up to 402.2 kWh/m² per year. Tests in more severe climates also showed that heat losses were lower than expected, confirming the effectiveness of the geometric design. However, the researchers point out that the model needs improvement to improve performance during water collection operations, and that further experiments are needed to understand the behavior of phase change materials (PCMs) under different climatic conditions. This study demonstrated the potential of using PCMs as an effective storage system in industrial control systems (ICSs)

Fig. 14. Experimental prototype setup.

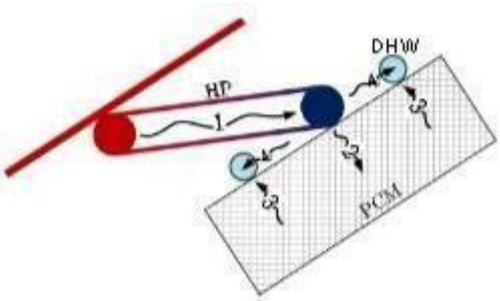


Fig.15. Principe of operation and main heat fluxes [14].

O. Ojike et al. [15] conducted a study to evaluate the performance of a passive solar air heater using palm oil and paraffin as a thermal storage medium. Two systems were evaluated, one using paraffin and the other using palm oil. The efficiency of two systems was measured over a 24-hour period (Figure 16) where the daily solar radiation ranged from 11.6 to 21.1 MJ/m2 during the experiment period and the air temperature ranged from 23.6 to 32.4 °C. The solar radiation and temperature data were evaluated on three different days where it was observed that November 10 recorded the highest level of solar radiation and temperature. A thermometer (MTM- 380SD) with K-type thermal conductors was used to record temperatures at different points of the systems at time intervals. Solar radiation was measured using a Kimo-solarimeter, model SAM 20, which measures radiation at 5-minute intervals. The results showed that the system using palm oil achieved a collection efficiency of 57.3% and an average efficiency of 46%. Compared to the system using paraffin, which achieved 46% and an average efficiency of 38.4%. Also, the high solar radiation positively affects the two systems. In addition, the palm oil system recorded higher temperatures compared to the paraffin system. Based on this, the researchers concluded that palm oil can be an effective option as a thermal storage medium in a solar air heater.

Fig.16. Solar air heater photograph.[15].

Bilardo et al [16], an experimental and numerical study was conducted on the performance of water heating with integrated collector storage (ICS), a preliminary model was designed for integrated collector storage that contains a PCM and a combination of an absorbent surface and heat pipes inside a pressurized shell in summer and winter in France, as shown in Figure (16.17). Polyethylene glycol (6000) (Tm=50°C_55°C) PCM was used due to its beneficial thermophysical properties, and a solar radiation meter and flow meter were used, the results were verified, they reached a daily production of 200 liters of hot water. Using six preliminary models with an area of three-square metres, two parameters were calculated, the annual solar energy rate and the stored energy rate. The annual solar energy saving rate reached 56%. Bilardo et al, investigated the model performance of an ICS containing a PCM in the collector and a DWH heat pipe using PEG , The coefficient of heat loss and transfer through the heat pipe was evaluated for the summer and winter seasons, With a collector area of 0.5 m^2 , the thermal storage reached a maximum temperature of 79.3°C , 0.02 m^3 of PCM section was able to store 24.57 KWh of thermal energy and the specific heat flow reached 2.64 KW $\cdot m^{-2}$ of DWH production at a water flow rate of 0.87Kg/min .

Fig. 17. Test bench outdoor installation. [16].

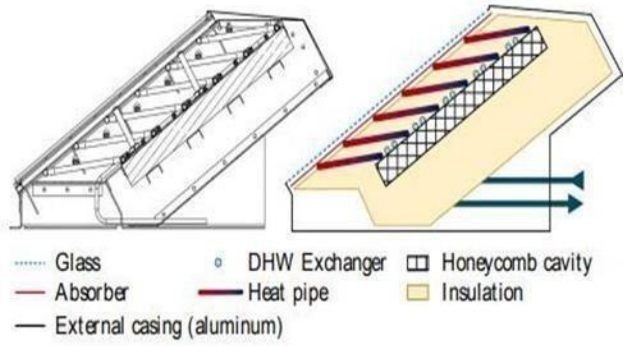


Fig. 18. Prototype main internal components (section view). [16]

While previous studies focused on comparing the performance of heat storage media such as palm oil and paraffin, other studies have addressed more advanced materials. Rok Stropnik et al. [17] evaluated heat storage systems using phase change materials (PCMs) and compared them with conventional heat storage systems. The researchers designed an experimental system to evaluate the performance of energy storage systems (Figure 18). A storage tank with a volume of 0.28 cubic meters was used, and the PCM modules were integrated into a cylindrical shape, which contributed to improved heat transfer efficiency. Figure 19 shows cylindrical modules made of PCM inserted into the storage tank. The results showed that heat storage systems using PCMs had a higher energy storage density and the ability to maintain a constant temperature (25°C) for a longer period of time, up to 300 minutes, as shown in Figure 19. It was observed that the design of the cylindrical modules affected system performance. The results also showed that increasing the PCM ratio led to higher stored energy density, while decreasing the tank temperature. Researchers have found that PCM heat storage systems offer significant advantages over conventional systems, making them a promising option for applications (such as heating in poultry houses).

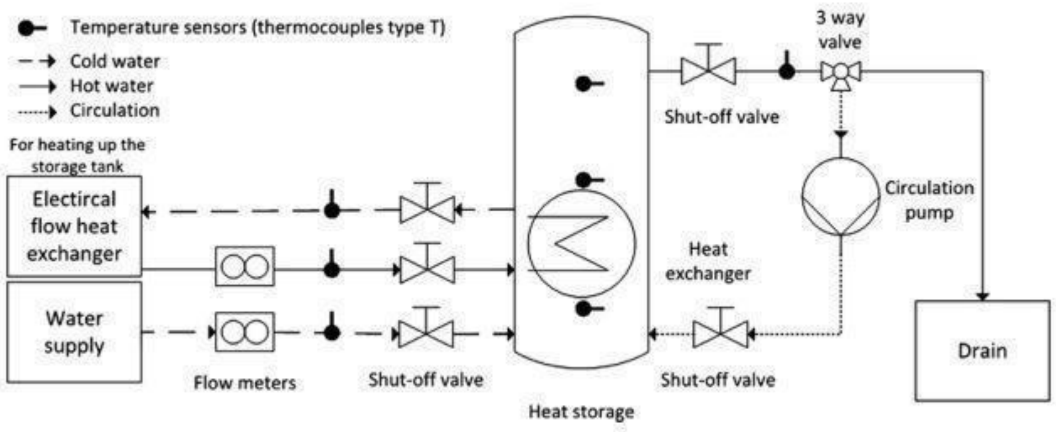
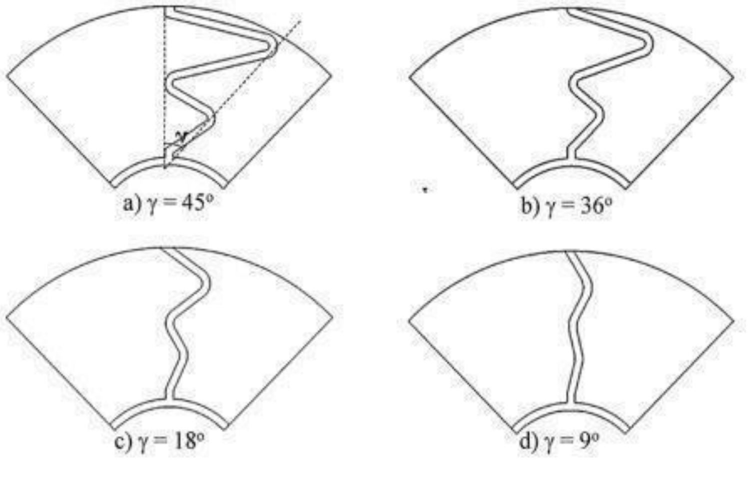


Fig. 19. Scheme of the experimental setup [5].

Fig. 20. Cylindrical modules inserted into storage tank [17].

Kareem Awny Aly et al. [18] improved the performance of latent heat angle thermal storage (LHTES) systems by using wavy fins. Numerical modeling was used to investigate the effect of fin shape on the PCM hardening rate in the tube region where the hardening time was significantly reduced by using wavy fins due to the increased fin length and heat exchange surface (Fig. 20). This makes it an interesting option for future research and development in this area.



a) $\gamma = 45^{\circ}$ b) $\gamma = 36^{\circ}$

c) $\gamma = 18^{\circ}$ d) $\gamma = 9^{\circ}$

Fig. 21. The investigated corrugated fin heights [18].

J. Izar-Tenorio et al [19], a simulation and evaluation of indoor houses for broiler chickens were conducted and the requirements for (HVAC) and operational resources (energy and water) were determined in light of changes in climate temperatures as shown in (Figure 21). A simplified and static one-story thermodynamic model was developed for climate change systems for heating and cooling in industrial broiler farming as inputs, these inputs originated from 20 GCMs for typical (8.5 RCP) and moderate (4.5 RCP) climate change scenarios in the eastern United States, assuming day-old chicks entered the CMIP5 barn at 32°C with subsequent reductions of 0.5°C per day until the house temperature reached 21°C. The model simulates energy consumption during incubation by adjusting the space used according to the age of the chicken, our results indicate that increased temperatures from climate change scenarios by mid-century will increase energy demand for cooling by 5.5 ± 1.8% (RCP 4.5) and 6.6 ± 2.1% (RCP 8.5), and reduce energy demand for heating by 9.0 ± 3.2% (RCP 4.5) and 10.3 ± 3.7% (RCP 8.5) with respect to 2018. Furthermore, our results suggest that warmer temperatures under climate change will substantially increase water withdrawals for evaporative cooling. However, there may be a point where cooling pads may not be efficient enough to cool down chickens and other innovative alternatives may be required.

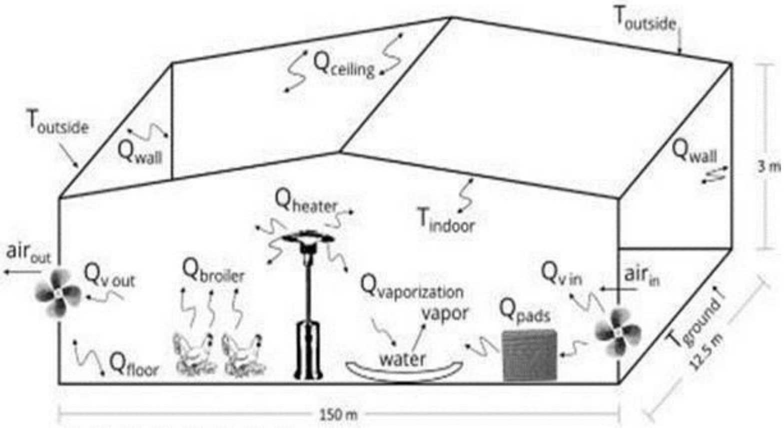


Fig. 22. Schematic of heat fluxes as modeled. [19].

In addition to the effect of tilt angles, the effect of internal design improvements was also studied and the study conducted by Hameed B. Mahood et al [20]. showed that adding fins to heat storage units can significantly benefit the thermal performan (Figure 22). Different fin angles and heights were tested, and it was found that the lowest angle of 15 degrees with a fin height of 0.8 radius was most effective in the melting process. The total melting time was reduced by about 50%. The results showed that there were low temperature gaps in the internal medium of the unit, indicating that there were restrictions in the heat diffusion during the melting process and that mixing the materials could lead to better acceleration of the melting of the materials. Paraffin (RT-50) was chosen as the phase change material (PCM) due to its stable, non-toxic and non-corrosive chemical properties, making it suitable for long-term applications.

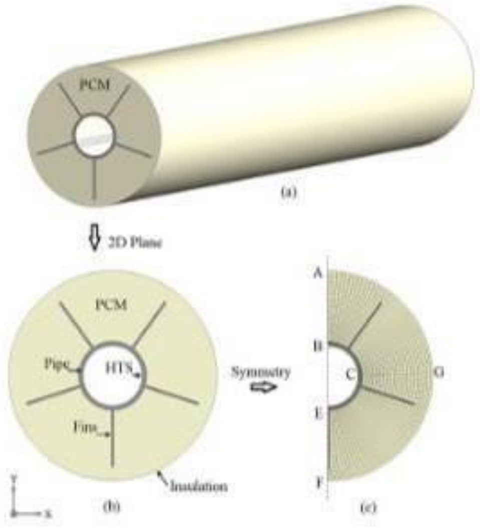


Fig. 22. Geometrical models for the present study (a) Three-dimensional diagram of horizontal finned double pipe LHTS; (b) Two-dimensional diagram of horizontal finned double pipe LHTS; (c) The computational mesh [20].

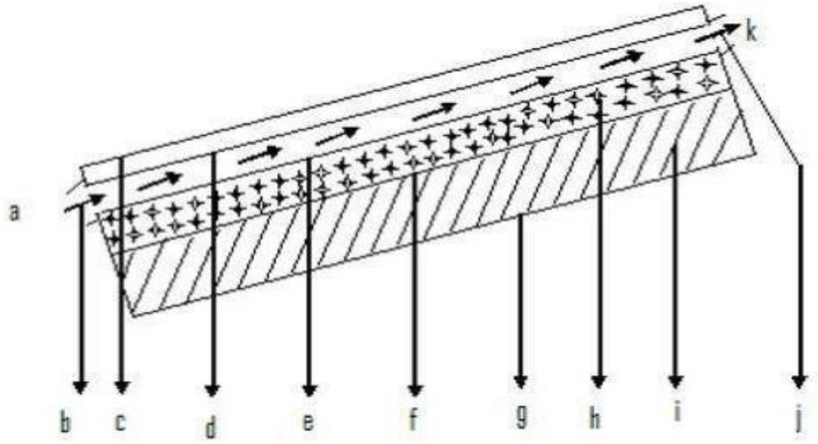


Fig. 23. Schematic diagram of the collector and heat storage subsystem [21].

Besides improving the heat storage efficiency, the researchers were also interested in evaluating the performance of a solar-powered poultry egg incubator with a phase change material (PCM) based heat storage system. The researchers E.O. Uzodinma et al [21]. conducted field experiments at the University of Nigeria (Figure 23), Nsokka where the temperature and humidity of the incubator were monitored under different climatic conditions for three different months which represents the solar radiation collected during three specific days of the incubation period. The days chosen were December 10, a sunny and dry day, March 16, a sunny and temperate day, and May 8, a rainy and cold day. The results showed that the system achieved an average hatchability of 62.3%, while maintaining the incubation temperature within the ideal range of 36-39°C showing the results of the different temperature measurements in the system and a continuous relative humidity within the required range (50-75%). The researchers found that using an incubator system that integrates a solar collector with phase change materials (PCM) for heat storage could be a sustainable and cost-effective solution to improving poultry production, especially in remote areas.

Vikas A. Yadav et al. [22] studied the topic of thermal energy management in poultry farms, focusing on energy consumption. Optimum temperatures were maintained between 21°C and 37.7°C during the poultry rearing stages to improve productivity and reduce heat stress. Special systems such as solar walls and solar collectors were suggested to meet the thermal energy needs of poultry, for water generation and heating, which helps in reducing energy consumption from conventional sources (Fig.24) Phase change materials (PCM) were used in thermal storage systems, to store thermal energy and control the temperature inside the farms during periods of climate change, which leads to improved bird comfort (Fig. 25). The study showed that the use of heat recovery techniques can reduce energy consumption in ventilation and heating systems.

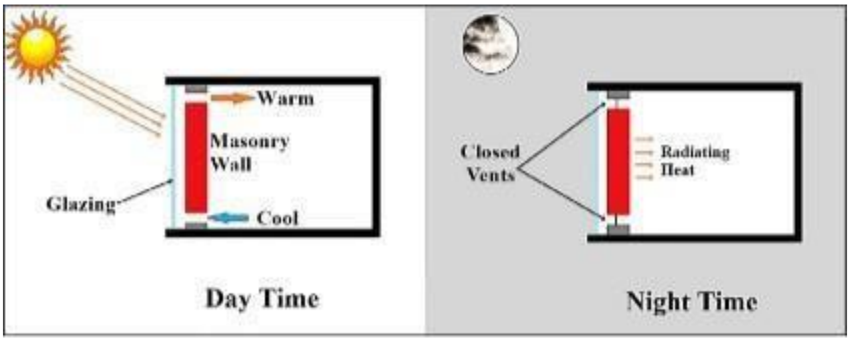


Fig. 24. A schematic showing the working of a conventional Trombe Wall [22].

Vikas A. Yadav et al. [22] studied the topic of thermal energy management in poultry farms, focusing on energy consumption. Optimum temperatures were maintained between 21°C and 37.7°C during the poultry rearing stages to improve productivity and reduce heat stress. Special systems such as solar walls and solar collectors were suggested to meet the thermal energy needs of poultry, for water generation and heating, which helps in reducing energy consumption from conventional sources (Fig.24) Phase change materials (PCM) were used in thermal storage systems, to store thermal energy and control the temperature inside the farms during periods of climate change, which leads to improved bird comfort (Fig. 25). The study showed that the use of heat recovery techniques can reduce energy consumption in ventilation and heating systems.

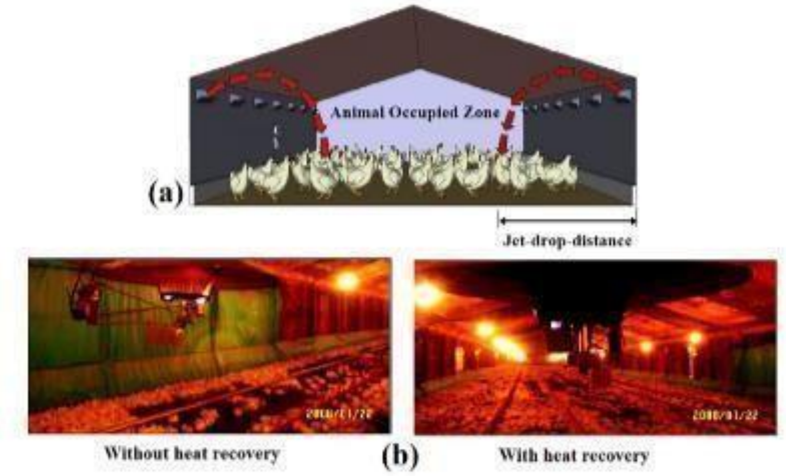


Fig. 25. (a) The jet-drop-distance (b) Effect of using heat recovery in brooder [22].

M. Fallah Najafabadi et al [25]. a study and analysis of the effect of some critical geometric and flow parameters on the PCM melting process was conducted. A double- solenoid concentric tube heat exchanger in which water flows in the inner tube as a heat transfer fluid (HTF) and RT-50 is located inside the ring as a PCM (as a thermal storage system) in solar water heaters in Iran was digitally designed as shown in Figure (26). and a numerical simulation of the heat exchanger was performed in Ansys Fluent 19 software implementing the algorithm "SIMPLE" and comparing it to academic friction , The outer surface of the tube was considered thermally insulated, and the flow of the heat transfer fluid in the inner tube was turbulent (using the k-ε RNG turbulence model to simulate turbulent flow) and the fluid entered at a temperature of 350 K and a speed of 3 m/s, flowing upward and creating a thermal storage unit in the unit , The most important outcomes of the investigation show that inlet temperature and inner and outer pipe diameter are critical factors for the storage system's design. A 1.5 % change in inlet temperature will enhance the melting rate by 27 %. Also, by increasing the inner pipe diameter by 42 %, the melting process was improved by 92 %, while the outer pipe diameter was inversely related to the melting rate. A 20 % increase in this parameter's value showed a 52 % reduction in the melting.

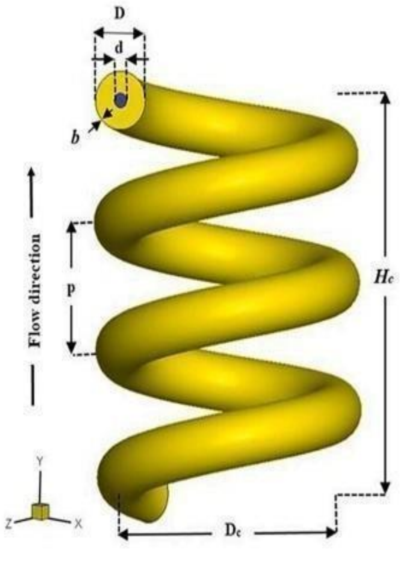


Fig. 26. The geometry of double-pipe helical coil heat exchanger. [25]

Moreover, the change in the helical pitch could not significantly affect the PCM melting process, and for a 300 % increase in pitch size, the melting process increases only by 0.6 %.

Yousra Boutera et al [26] , A study was conducted on a proposed air- ground heat exchanger system to cover the needs of the living environment and reduce energy consumption and greenhouse gas emissions in an industrial poultry house in southern Algeria, to reduce energy consumption in poultry houses and the environmental impact using the proposed EAHE system to cool and heat this type of building (Figure 27) , the experimental data for this study were collected from a poultry house belonging to Salem Poultry Group (Figure 27) . Heating and cooling requirements were determined; the soil temperature distribution was analyzed to determine the optimum depth for installing the proposed system. a parametric and economic study was presented to determine the dimensions and cost of the EAHE. Finally, a study was conducted to compare the proposed system with the systems used in poultry houses in terms of thermal efficiency and its impact on the environment during the hottest and coldest times of the year, The study results, which were obtained in extreme working conditions, showed that the earth air heat exchanger could cover 45% and 38% of the heating and cooling demands, respectively. In summer, the proposed heat exchanger was able to reduce the temperature from 47°C to 27.1°C, while in winter, it was able to increase the temperature from 4.8°C to 22.9°C, and its performance was stable compared to the systems currently used, and, it recorded temperatures better under hot outside conditions. Furthermore, its use reduces CO2 emissions to 719 kg_{CO2}/day in heating and 2531 kg_{CO2}/day in cooling, making it a suitable solution for this type of industrial building.

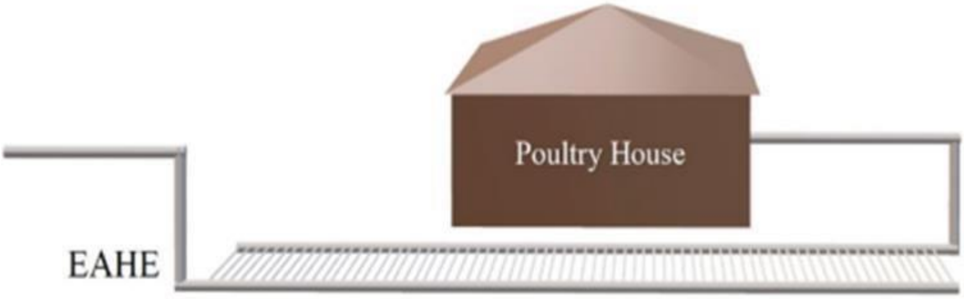


Fig.27. Scheme of the EAHE system. [26]

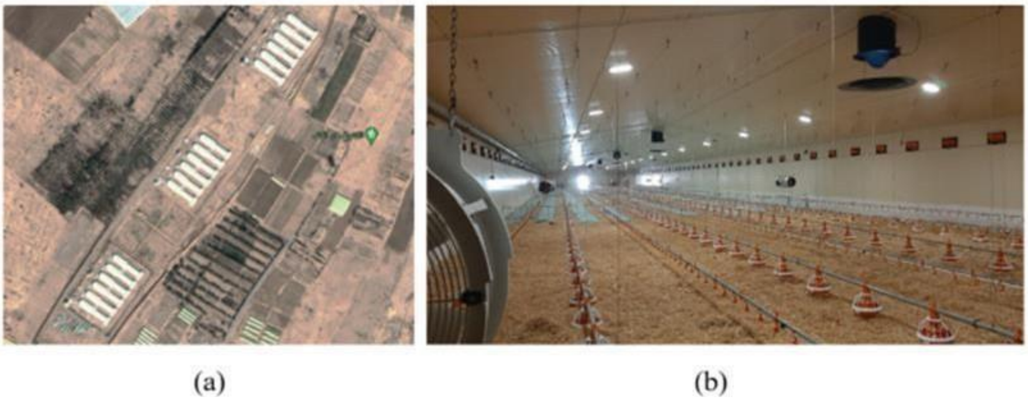


Fig. 28. (a) Aerial view of the poultry farm and (b) inside view of the poultry house, Salem Poultry Farms, Sidi-Okba, Biskara, Algeria, where the study was conducted. [26]

Leandra Vanbaelinghem et al [27]. emphasized the rapid growth of global livestock, including egg production, and the use of non-renewable energy in its production, and addressed the operation of heating, ventilation and air conditioning systems due to the large part of their use. To address this and reduce the necessary energy use to reduce the environmental impacts of intensive production, energy simulations were conducted to estimate typical thermal loads for poultry housing systems in cages and free-range farms in various Canadian locations, and to identify them as market-ready alternatives that could be applied in the industrial egg sector with a particular focus on their use in temperate and continental climates (see figure 28). These estimates were used to evaluate alternative systems in terms of: (1) their ability to meet the energy requirements of egg production facilities, (2) their potential to mitigate environmental impact, and
(3) their relative affordability by considering insights derived from a systematic review of 225 relevant research papers, The results showed that future research should prioritize ground-air heat exchangers as a complementary system and ground-air heat pumps as a stand-alone system to reduce the impacts associated with the operation of conventional HVAC systems in egg production.

I.3. Conclusions

The results of previous studies and researches showed that heating systems achieve a significant improvement in energy efficiency in poultry houses, while maintaining an ideal thermal environment for poultry and other environmental conditions. These systems were found to contribute to a significant reduction in energy consumption, while maintaining suitable temperatures for poultry, which leads to improved growth rates, productivity and reduced mortality rates. Previous studies open a clear path for the future development and improvement of poultry farming practices by taking advantage of renewable energy technologies, through the possibility of developing more efficient and sustainable systems.

Chapter II

State of the art: Heating systems for poultry.

II.1. Introduction

Efficient production performance of a broiler flock is affected by ambient temperature, humidity, heating or cooling system, and the environment of the broiler house, Heating broiler houses is essential in winter season. During the winter, the average temperature is generally below freezing, where birds are exposed to cold stress. Researchers have shown that cold stress significantly influences the health, well [28].

One third of the animal protein currently consumed in the world derives from chicken meat Broilers. Heating inside poultry houses is an essential part of ensuring bird health and achieving maximum chicken growth. Heating systems differ in their source of energy, location of the equipment, heat carrier, and method of heat transfer in heated spaces. Based on the location of the device that provides the heat, heating systems are classified in local, central and district heating systems. Most systems have as a source of energy solid fuels, gaseous fuels, diesel oil or electricity [29].

The comfort zone is defined as the temperature zone in which the birds are able to keep their body temperature constant with minimum effort. This temperature zone also depends on the feeding level and housing conditions. Behaviour of birds will change when temperatures rise to above the comfort zone as they will start to pant and change their body position. When temperatures are below the comfort zone birds will also change their body position and huddle together [30].

40–60% of the total deaths are caused by emissions of heating systems regardless of other health injuries. This is due to the high dependency in rural China on solid-fuel heating systems that have high pollutant emissions and mainly $PM_{2.5}$ and polycyclic aromatic hydrocarbons (PAH) that lead to an increase in cancer risk. Recent research studies tend to focus on investigation of heating system emissions using modern accurate techniques, in winter, heating systems depend almost on fossil fuel energy such as coal, oil, and natural gas. This is accompanied by severe environmental risks such as gas emissions, global warming and noise pollution. Due to these serious negative impacts, it is utmost necessary first to focus on the large heating systems which is the case of district heating. This is also very crucial because of its rapid growth and spreading. Thus, endeavors have been recently encouraging to use alternative heating systems based on renewable energy sources such as solar and geothermal [31].

II.2. Traditional poultry house heating systems

Traditional heating systems are simple and easy to operate methods that have been used since ancient times to provide heat and warmth inside homes, buildings and barns (such as poultry houses) (Figure1) in the winter. They relied on fossil fuels and natural energies and were characterized by less efficiency, higher energy consumption and the production of harmful and polluting emissions that affect the environment and the health of birds.

FigⅡ.1: Broiler shed interior [30].

II.2.1. Heating systems using solid fuel stoves and heaters

In the past, fuel stoves were commonly used. Was the application of small, domestic-scale stoves as a heat source for daily activities (heating house) is widespread all over the world. Depending on regions, and fuel resources, different fuel types are used [32], household burning of solid fuels in traditional stoves is detrimental to health, the environment and development, these solid fuels are typically burnt in traditional, inefficient stoves causing high levels of household air pollution (HAP) [48], It requires regular maintenance.

II.2.1.1 Wood heating system

Wood stove (Figure 2) operates as a closed combustion unit for wood. Of the poultry houses use firewood for heating, due to its availability and low cost [33]. Among them are wood-fired ovens The furnace is the part of the combustion appliance were burning of the solid fuel actually takes place found Fuel is automatically injected into the furnace, combustion air is added, and the fuel burns to produce heat [34]. Converting to woodburning stoves in an effort to reduce winter heating bills. documented hazards associated with the use of wood burning stoves include accumulation of carbon monoxide as well as an increased number of burn injuries and house fires [33], but studies show that it generates a greater amount of greenhouse gases and more energy. Combustion gases generated by brooding during the starter phase of the broiler rearing cycle increase house temperature above the external environmental temperature, carrying vaporized firewood moisture and vapor produced by combustion. In addition to CO2, H2O and N2 emissions generated by complete wood combustion This negatively affects the health of poultry, the coal-fired system as the worst among all heating systems regarding the impacts on the environment [31].

Fig II.2: Heating poultry farms with peat and firewood.

II.2.1.2. Coal heating system

Coal is a solid fossil fuel that has been used as a heating material for barns. Coal has been used for residential heating for centuries. In the middle of the last century, coal use for residential heating was widespread [35], it is classified as a traditional system that relies on burning coal as the primary source of heat to ensure the comfort and well-being of poultry inside the barn. and coal oxidation at low temperatures is the heat source liable for the self-heating and spontaneous combustion of coal involves oxygen consumption and formation of gaseous and solid oxidation products. This process is majorly influenced by temperature, oxidation history of coal, coal properties, particle size distribution of the coal, etc. [36]. and global meta-analyses of epidemiologic studies indicate that indoor air pollution from solid fuel use is responsible for premature deaths annually that reported health effects, exposure characteristics, and fuel/stove intervention options. Observed health effects, resulting from the use of "poisonous" coal have been observed, Limited to suspended particles, carbon monoxide, sulfur dioxide, and nitrogen dioxide [37].

- **Coal boiler heating systems**

old-type boilers emit higher concentrations of substances related to incomplete combustion, such as particles, CO and hazardous compounds (e.g., polycyclic aromatic hydrocarbons) [38]. Combustion of coal for residential heating is an important source of outdoor (ambient) air pollution. However, it can also cause significant indoor air pollution either through direct exposure (e.g., a chimney draught in poor condition) or due to infiltration from outside (through windows and building cracks). The International Agency for Research on Cancer (IARC) classified indoor emissions from the household combustion of coal as carcinogenic to humans. In addition, coal combustion produces Sulphur dioxide and toxic pollutants. Furthermore, coal also contains dangerous elements [39]. The quality of emissions formation during the combustion process is affected, especially by the combustion technology, the fuel used and the user operation. It has also been shown that boilers, operating with a reduced output, work less efficiently and emit more harmful gaseous compounds and particles, originating from incomplete combustion, and heat outputs of boilers were set on 30%, 60% and 100% of the nominal output (Figure 3) [38].

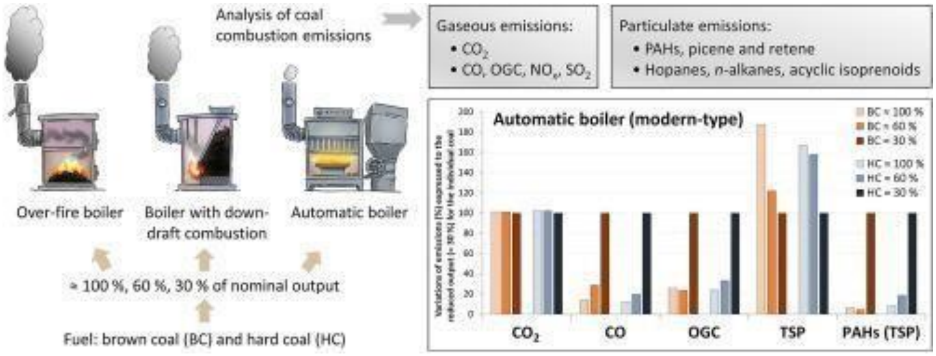


Fig Ⅱ.3: Heat outputs of the three boilers [38].

- **Coke coal or the remains of pressing olives heating system**

Most poultry farms use coke (Figure 4,5,7) or charcoal burners to heat their barns. This is due to several reasons, including the fact that these burners rely on inexpensive materials compared to other heating methods, their low malfunctions compared to other heating systems, and their simplicity in principle. These burners are operated by workers multiple times a day, or they have a small tank next to them It gradually supplies the combustible material. There is also a specific fan known to poultry owners as the "kur." This fan is a small fan connected to a metal tube that continuously pushes air into the burner to aid ignition. Another drawback of these burners is the potential for leaks. This can occur as a result of wear and tear on the burner itself or the pipes (pipes) that exhaust the smoke from combustion outside the barn. This can then lead to the leakage of these gases and fumes, which contain carbon monoxide and carbon dioxide, into the barn and then into the birds' respiratory systems. Poisoning from these gases can occur through inhalation, leading to death, especially in the early stages of hatching. This can cause severe respiratory problems, sometimes leading to chick incubation. Some of its drawbacks also include the need for frequent and periodic cleaning, as well as the need to scrape and open the air intake holes at the bottom of the burner, which are closed due to the continuous settling of molten coal. This cleaning process (Figure 6), in all its stages, may result in some coal particles falling, no matter how small, and being picked up by some birds, who ingest them, causing coke poisoning that inevitably ends in the bird's death [40].

Fig Ⅱ.4: Coke used for heating in poultry houses [40].

Fig Ⅱ.5: Traditional coke stoves with coal storage tank [40].

Fig Ⅱ .6: The lower openings in coke burners circulate air to increase combustion. These must be cleaned regularly and carefully [40].

Fig II. 7: Illustrates the placement of additional barrels and exhaust pipes to increase the thermal radiation generated by coal stoves [40].

II.2.2. Gas heater heating systems

For many years, the broiler industry in developing countries has relied on direct heating systems using gas burners that direct heat toward the broiler chickens to maintain their thermal requirements, especially during the first two to three weeks of life. when outside temperatures drop, sufficient warmth must be provided for a comfortable poultry house environment [41]. Among them are traditional gas-fired boilers, A conventional boiler primarily consists of a combustor and a heat exchanger: the heat generated from the combustor is supplied to the heat exchanger via water or steam at high temperatures [42].

II.2.2.1. Natural gas heating systems

Heating on some farms previously relied on natural gas pumped through a pipeline network. It is a heating system that uses gas to provide optimal temperature in the poultry farming environment. These systems convert gas into heat and direct it into the farm, helping maintain stable temperatures that are conducive to the health of the chickens. These systems are particularly used during cold winters to ensure that the chickens remain warm and healthy. The use of a gas heater improves chicken survival rates The most prominent disadvantages facing these types of heating systems were the cost and greenhouse gas emission and increases the microclimatic carbon dioxide concentrations that adversely affect performance, behavior, carcass yield, immunoglobulin concentration, and bacterial counts and prevalence and feed conversion ratios revealed highly significant increases and As, the highest duration and frequency of locomotion and panting was recorded in broilers raised in the room supplied with the gas-operated system. It had the following advantages: revealed highly significant increases of weight gains and performance indices [41].

II.2.2.2. Liquefied Petroleum Gas (LPG) heating system

Liquefied Petroleum Gas (LPG) are the main fuel used for heating, particularly for brooding. among them are gas-powered heaters (Figure 8,9), which consist of a coil fed with gas and radiating heat. Behind it is a reflective metal plate to prevent the scattering of thermal radiation. However, their energy source is liquefied petroleum gas (propane/butane). Therefore, one of the conditions for using these heaters is good ventilation in the coop to ensure that the birds are not poisoned by the smell of gas when these heaters are operating normally or in the event of a leak. These heaters are often criticized for gas leaks, but some companies have equipped these heating systems with sensors that detect gas leaks and immediately turn off the heater and stop the gas supply [43].

Fig II. 8: Gas heaters in poultry houses [40].

Fig II.9: Gas heaters in poultry houses [40].

II.2.3. Electric heating systems

It is considered one of the cleanest and easiest heating methods, but it is plagued by its high cost and the heat it emits may be released through radiant tubes or by fans electric heating is an attractive low-cost method for residential heating for areas having ample supply of electricity that produces low greenhouse gas emissions. On the other hand, one could argue that producing heat with a thermal resistance may not be the most sustainable way to maintain thermal comfort from an energy quality point. Electricity is a high exergy energy type, as such, converting the electricity to heat, a low exergy energy, could be interpreted as a poor use [44].

II.2.3.1. Heating systems with electric heaters

Electric heaters (Figure 10), such as those we use in homes, consist of a coil that is powered by electricity and radiates heat. Behind it is a reflective metal plate to prevent the dispersion of the heat radiation and direct it only in the desired direction. The disadvantage of this heating method is that it increases electricity consumption on the farm and in areas that experience frequent power outages. The use of such heating sources increases the use of electric generators Heating systems of this type require constant maintenance due to frequent power outages, as well as the wires used in them [40]. It is well known that electric heaters convert 100% of their power into heat. This has generally been interpreted in the engineering community that electric heating systems all have the same efficiency. Although it is true that they all convert power to heat as efficiently, they do not distribute the generated heat in the same way. [44]

Fig II.10: Electric heaters in poultry houses [40].

II.2.3.2. Heat lamp heating systems

Most livestock barns are heated using radiant heat lamps to maintain the temperature. However, these lamps have high operating costs (electricity consumption) and are usually applied only for creep heating. Another factor is that heat lamps can potentially cause fires [45]. Further, radiative heat can encourage to spend more time resting in a safe area of the stall that can result in reduced crushing and decreased issues related to hypothermia. While supplemental radiative heat can improve thermal environmental, reported decreased feed intake when heat lamps mounted above a plywood floor covering were placed beside the crate versus in the front stall during lactation. This could indicate that the additional heat radiated induced heat stress, thereby repressing feed intake [46].

II.2.4. Diesel heating systems:

Conventional boiler which runs on the combustion of diesel fuel (Figure 11) has been around for two centuries [47]. It is a heating system that relies on using fuel classes as a heat source, where the fuel is burned inside a boiler in order to heat water or air and then the heat is distributed from it through systems such as pipes or ducts in order to spread the warmth throughout the building, which helps enable this system with places far from the gas network. There are boilers that operate on a mixture of diesel and biodiesel, which is considered a traditional technological system and they are:

- **Diesel / Biodiesel Boiler Heating System:**

Biodiesel is widely accepted as a fuel that is similar to diesel with various advantages, Biodiesel's low-temperature flow qualities are one of its characteristics that limits its use [49]. Biodiesel is a ‘diesel-like’ fuel that is derived from processing vegetable oils from various sources, such as soy oil, rapeseed or canola oil, and also waste vegetable oils resulting from cooking use.

Fig II.11: The Diesel fired furnace during testing [43].

Brookhaven National laboratory initiated an evaluation of the performance of blends of biodiesel and home heating oil in space heating applications under the sponsorship of the Department of Energy (DoE) through the National Renewables Energy Laboratory (NREL). were environmental benefits from the biodiesel addition in terms of reductions in smoke and in Nitrogen Oxides (NOx) [50]. When used in conventional diesel engines, biodiesel reduced emission of HC, CO, and particulate matter. Biodiesel is green and clean fuel, containing in built oxygen and without containing Sulphur, allowing it to burn completely with less oxygen. Even when combined with petroleum diesel, the cetane number is increased [49].

II.3. Modern Poultry House Heating Systems

Modern poultry house heating equipment is a sophisticated technological development, specifically designed for poultry thermometers. These systems feature low operating costs, while taking into account their impact on the environment and bird health. They also feature precise temperature control, thermal preference, and energy efficiency, distinguishing them from conventional heating technologies (such as gas-fired or non-directional heaters).[51]

II.3.1. Renewable Energy Heating Systems

Energy produced from fossil fuels increases greenhouse gas emissions into the atmosphere, which in turn highlights renewable energy sources as viable in poultry production.[52]

II.3.1.1. solar heating systems

- **Solar Thermal Heating Systems**

Mirrors that reflect sunlight and concentrate it onto receivers are used in high-temperature solar thermal heating technology, often known as concentrated solar heating (CSP). The receivers convert solar energy into thermal energy, which in turn drives a heat engine or steam turbine.

CSP systems can also produce chemical fuels for industrial activities, storage, and transportation. Areas with strong vertical direct solar radiation are ideal for CSP systems.[53]

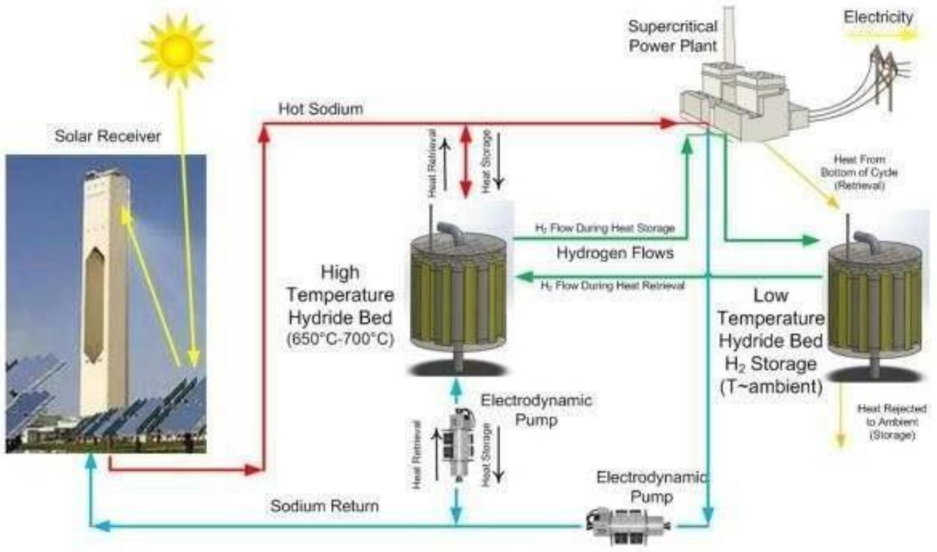


Fig Ⅱ.12: High-Temperature Solar Thermal [54].

The simplest way to harness solar energy resources is through low-temperature solar technology, which operates at temperatures up to 100°C. Both active and passive systems can be used. Heat is transferred from the solar collector to the final step in active conversion systems using a heat transfer system. Passive systems use the solar energy source for lighting and heating without the need for active components. This section focuses primarily on active systems that use solar radiation to generate thermal energy for space heating, cooling, and water heating. These systems store energy using storage tanks.[54]

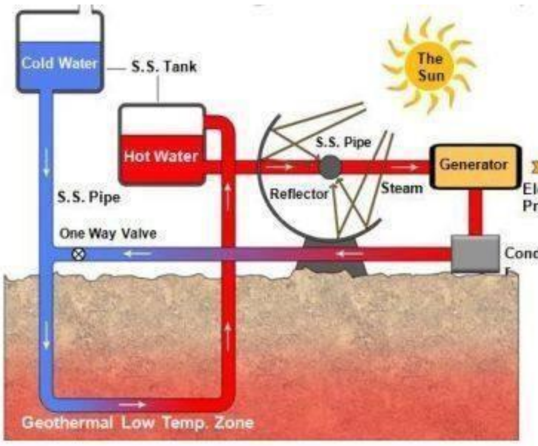


Fig Ⅱ.13: High-Temperature Solar Thermal [54]

- **Photovoltaic Solar Heating Systems**

In fact, the word "photovoltaic" is derived from the Greek word’s "photo" meaning "light" and "voltaic" meaning "light." Therefore, "photovoltaic" literally means "electricity of light." Solar photovoltaics convert heat into electricity. This system is used to power heating systems. The heat storage technology used in solar photovoltaic systems also improves capacity and provides continuous heating, even in the absence of sunlight [55].

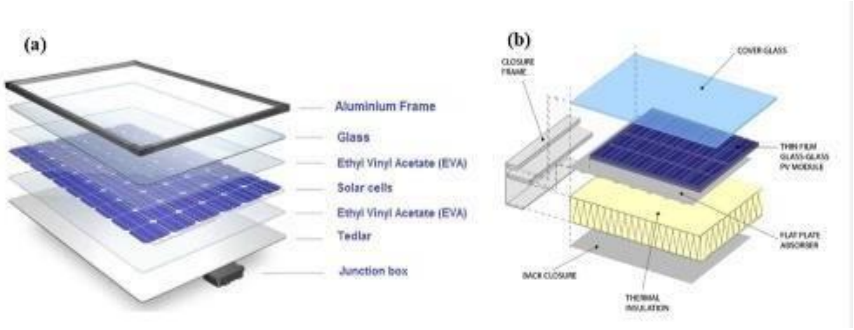


Fig Ⅱ.14. The schematic diagram of solar energy technologies: (a) PV; (b) PV/T [55].

- **The working principle of solar panels**

Photons penetrate slightly fine optical "beads" of silicon, displacing some electrons from the metal. Electrons can only flow in one direction through the semiconductor metal. To return to their original position, the electrons moved by the light must pass through the external circuit, generating an electric current. Even in cloudy conditions, the cells generate electricity daily; however, their efficiency declines. The cells are assembled together to make photovoltaic panels, which are installed inside homes or on roofs. Superior technical efficiency is essential for the complex manufacturing process to ensure excellent long-term performance. These solar cells are built in contact with each other [56].

II.3.1.2. Biomass Heating Systems

The use of biomass heating contributes significantly to poultry production and reduces reliance on fossil fuels. The material, known as biomass, can be converted or processed to provide energy. Biomass is a material obtained from plants and animals that can be chemically converted or gasified and used directly for heating [57].

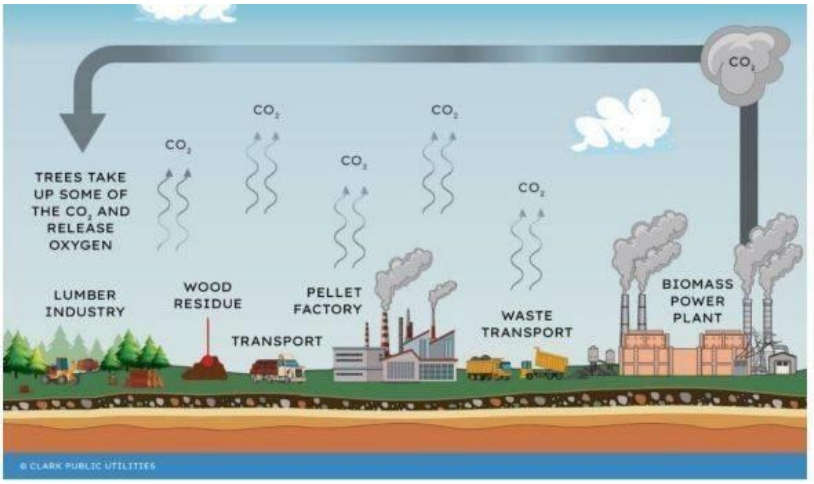


Fig.15: The Biomass cycle [54]

- **Poultry Manure:** It is more profitable to use chicken manure, a waste product, as fuel to produce heat and electricity, especially for poultry farms. Chicken manure can be effectively utilized in anaerobic digestion and pyrolysis processes. On the other hand, chicken manure can be used as fuel for on-site combustion processes, using bio combustion systems to generate heat in poultry houses [58].
- **Biogas for heating poultry houses:** The process of producing biogas from biomass involves two main processes: Decomposition of organic matter: known as the anaerobic digester The anaerobic digestion of this waste takes place in three steps. In the first step, the chicken manure is placed in a laboratory digester without prior treatment. In the second step, the droppings are placed in an industrial digester without pretreatment. In the third step, a methanogenic inoculant is incubated with the chicken droppings in a batch digester. Biogas production is measured using a manometer, and its composition is analyzed using gas chromatography [59].
- **Biogas production:** This is achieved by microbial decomposition and fermentation of organic matter found primarily in the droppings. The resulting gas consists mostly of carbon dioxide and methane. It can be used as fuel for heating systems in poultry houses. This system helps maintain a comfortable temperature inside poultry houses and reduces carbon dioxide emissions and harmful substances compared to conventional systems [60].

II.3.1.3. Geothermal Energy

Due to the increasing use of fossil fuels, research has been conducted into alternative sources. Geothermal energy, which is a combination of two Greek terms: "geo" (earth) and "therm" (heat), describes the warmth generated within the Earth, located two to three meters below the surface, for heating and cooling. It has been found to be less expensive than solar energy [61].

Fig II.16: Geothermal energy.

II.3.1.3.1. Working principle of geothermal energy

The soil temperature remains relatively constant throughout the year, ranging between approximately 22 and 24 degrees Celsius below the Earth's surface. Heat is extracted from the ground using heat pumps that pump a coolant through underground pipes. The pipes then distribute the heat energy throughout the poultry house [62].

II.3.1.3.2. The main components of a geothermal energy system

An electrically powered device, known as a heat pump, transfers heat from a source—a place with a lower temperature—to the poultry houses, which have a higher temperature. Geothermal heat pumps consist of two main parts: a heat pump and a ground-based heat exchanger. These pumps feature a single heat exchanger inside the house, unlike air-cooled heat pumps [63].

II.3.2. Infrared Heating Systems

Infrared heating systems provide a sensitive and transparent environment for chicks, facilitating production and comprehensive monitoring. Infrared is a type of electromagnetic radiation that uses waves to transmit energy through the atmosphere [64].

Fig II.17. Schematic diagram illustrating the operation of the heating radiator used in the poultry house [73].

II.3.2.1. Operating Principle of Infrared Heating Systems

Chicks absorb the energy generated by radiant heaters immediately upon switching them on. Additionally, the hay below them is heated, raising its temperature and providing an ideal warm environment for chicks [65].

II.3.2.2. Basic Components of Infrared Heating Systems

- Canopy
- Emitter
- Stove
- Ignition System
- Thermistor

These basic components provide a range of radiant heating systems that help improve the poultry environment during the various stages of production [65].

II.3.2.3. Advantages and Disadvantages of Infrared Heating Systems

Infrared heating systems create thermal gradients, allowing chicks to select the area that provides maximum comfort as needed. However, if a single heater fails, 25% of the total heat source may be lost, which can lead to humidity and chilling problems for the chicks [65].

II.3.4. Temperature and Humidity Control Systems

Temperature and humidity control pose many challenges for heating, ventilation, and air conditioning (HVAC) systems, which are widely used in small and medium-sized buildings. Due to the small size of these systems, it is difficult to install a reheater or dehumidifier separately. Furthermore, regulating both temperature and humidity in a single unit is difficult due to the close interconnection between the temperature and humidity control circuits [66].

II.3.4.1. Heating, Ventilation, and Air Conditioning Systems

A building's heating, ventilation, and air conditioning (HVAC) system consumes the most energy. Therefore, increasing the efficiency of the HVAC system leads to greater energy savings in the building. Indoor temperature, air leakage, window type, window-to-wall ratio, and interior loads directly affect HVAC systems' energy consumption. Climate and building type are other factors. According to studies, properly selected and operated HVAC systems can save up to 25% on energy costs while maintaining a comfortable indoor climate [67].

II.4. Heat Storage Systems

The importance of heat storage technologies is growing in this century due to the depletion of conventional non-renewable energy sources, increasing environmental pollution, and the unstable availability of renewable energy sources, including solar and geothermal energy. Systems that enable the collection and storage of thermal energy (whether generated by industrial processes, exhaust air conditioning systems, or natural sources such as the sun) for a predetermined period of time for later use are known as thermal energy storage (TES) systems. These systems store heat using a variety of physical concepts [68].

II.4.1. Types of Heat Storage Systems

II.4.1.1. Chemical thermal storage systems

A technology that uses a chemical process to store energy. In an endothermic chemical process, thermal energy is absorbed and released in an exothermic reaction. Due to its maximum energy storage density, the system provides long-term, compact energy storage in a designed environment without the need for extensive thermal insulation [69].

II.4.1.2. Sensitive thermal storage systems

These systems are used in many applications due to their ease of use and simplicity. This process uses the heat charged within the system to change its temperature. Due to its low energy density, it is often susceptible to thermal energy leakage [70].

II.4.1.3. Latent Heat Storage Systems

Thanks to their large storage capacity per unit volume, small thermal fluctuations, and isothermal properties during charge and discharge cycles, latent heat storage based on PCM technology can be used in a variety of fields. Also known as phase change heat storage (PCM), it features high storage density and requires less weight and volume, making it relatively less expensive. In addition, the latent heat can be stored as heat of fusion at approximately the same temperature, which is equivalent to the phase transition temperature of the phase change material [71].

PCM-based latent heat storage can be used in a variety of applications. It can also be used to heat poultry houses by integrating it with heating systems.

II.4. Conclusion

In short, this chapter shows that improving heating systems in poultry farms plays a decisive role in providing a healthy and enjoyable environment for birds, which in turn improves their performance and productivity. With the increasing environmental issues and increasing anxiety over pollution caused by the use of fossil fuels, the transformation into sustainable heating methods, such as solar energy and ground thermal energy, is essential and urgent. It also stresses the need for modern technologies that guarantee high efficiency in heating, reduces energy consumption and operating costs, while maintaining safety and reducing the risks associated with traditional heating. Adopting advanced renewable heating systems not only contributes to environmental protection, but also improves bird health, promotes sustainable growth in the poultry sector, and supports food security.

Chapter III

Experimental Approach

III.1 Introduction:

To ensure the health and growth of birds raised in poultry farms, it is essential to maintain an optimal temperature. Fossil fuels and other conventional heating technologies can be expensive and environmentally harmful. However, solar heating systems offer a more environmentally friendly alternative. These systems use heat collectors and solar panels to convert sunlight into thermal energy to heat poultry housing.

To conduct this experiment, we built a prototype chicken coop measuring 3 meters long, 1.77 meters wide, and 1.55 meters high. A heating system consisting of ducted pipes, glass panels, and black-painted iron panels was installed.

We measured carbon dioxide levels, temperature, and humidity levels. This chapter presents and discusses the graphs that illustrate the results of each experiment as a measurement.

III.2 Hardware used:

III.2.1 Prototype construction:

We used sandwich panels to build a prototype for our pilot study (Figure III.1).

6 cm thick for their ease of installation and ability to reduce heat loss. The following table shows the characteristics of these panels.

	thickness	weight	Resistance to the Conductivity	coefficient of thermal Transmission
Sandwich panels	*60 mm*	$11, 42\ Kg / m^2$	$2{,}95\ 1/\Omega$	$0, 29\ W / m^2\ K$

Fig III.1: Photos of sandwich panel used in the walls of the prototype.

To maximize protection from solar radiation in our area, the prototype chicken coop's roof was designed to resemble a triangle. Following the design, we fixed the panels after cutting them on each side and assembling them with specific corners.

using rivets. After the prototype was constructed, the real photo is displayed in Figure III.2.

Among the components utilized are aluminum, glass, black-coated iron, and wooden panels. tubes with terraces and stabilizers.

- The infrastructure of the system is built using wood panels. Wood is a sturdy and lightweight material that supports the other parts and helps to insulate the system from heat buildup.

Fig III.4: Wood panels

- Black-coated iron panels: are the system's main heating element. The black coating improves the panels' ability to absorb sunlight and efficiently convert it into heat. The location of these panels allows them to directly heat the air within the system.

Fig III.5: Black coated iron panels.

- Glass panels: Cover the sides and top of the wooden construction. Glass panes enhance the heating process by letting in sunlight and trapping heat.
- Aluminum Stabilizers: For the safe assembly and installation of glass, iron, and wood panels. As a stainless steel, aluminum has excellent structural stability.

Fig III.6: Aluminium Stabilizers.

Hot air is transferred from iron panels to a little replica of a chicken coop using a listed tube. This tube offers a way to regulate the temperature within the chicken house and facilitates the effective movement of hot air. There may be a mechanism in the tube to modify the air flow and guarantee that is dispersed equally.

Fig III.7: Aluminium Pipe Listed

To heat the surrounding air, the system absorbs sunlight from black-coated iron panels. This heat is retained by the device using glass panels. Through a dedicated duct, the heated air is sent to a model poultry house, where the heat is efficiently distributed to create a warm environment for the chickens. This integrated design ensures efficient and sustainable solar heating, using the materials available to us most efficiently.

III.2.4. Discrimination of measure:

We utilized several sensors in our prototype to monitor temperature, humidity, and carbon dioxide levels inside the poultry house. These sensors were programmed using an Arduino board, enabling us to collect data with high accuracy and efficiency. They are also available at reasonable prices in our local market (EL-Oued area). Below are some photos and specifications of these sensors, which include:

III.2.4.1. DHT22 sensor:

The DHT22 is a digital sensor designed for precise measurement of temperature and humidity. It supports a temperature range from -40°C to +80°C with an accuracy of ±0.5°C, and a humidity range from 0% to 100% with an accuracy between ±2% and ±5%. The sensor updates its readings every two seconds and operates on a voltage range of 3.3 to 5.5 volts. Thanks to its digital output and ease of integration with systems like Arduino, the DHT22 is a reliable choice for monitoring environmental conditions in farmhouses and poultry houses, helping to enhance indoor climate control with accuracy and efficiency.

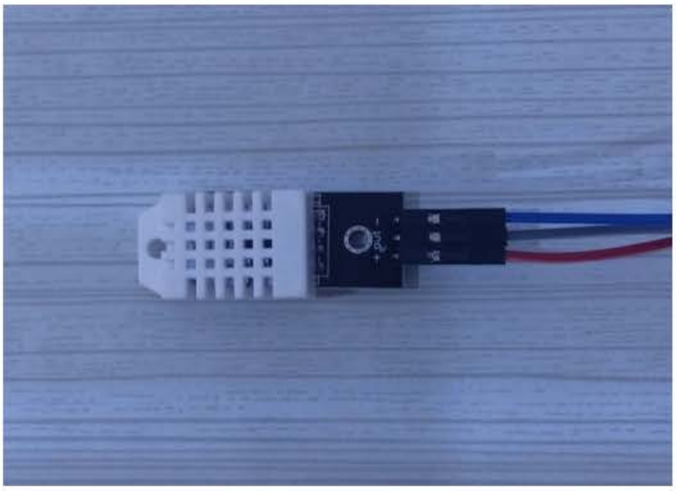


Fig III.8: DHT22 sensor.

III.2.4.2 CO2 sensor (MQ135):

The MQ135 is an air quality sensor capable of detecting a variety of gases, including carbon dioxide (CO_2), ammonia, and alcohol. It operates on a 5-volt power supply and is known for its high sensitivity and quick response time, making it well-suited for environmental monitoring, ventilation systems, and health-related applications. With its analog output, the sensor can be easily integrated with microcontroller platforms such as Arduino and Raspberry Pi, making it a widely used solution for assessing air quality in confined environments.

Fig III.9: CO2 sensor (MQ135).

III.2.4.3. Arduino Nano ESP32:

The ESP32, developed by Espressif Systems, is a powerful microcontroller featuring advanced Wi-Fi and Bluetooth connectivity, making it an excellent choice for Internet of Things (IoT) applications. It is equipped with a dual-core processor running at up to 240 MHz, 520KB of RAM, and supports a wide range of input/output interfaces including GPIO, ADC, DAC, SPI, I2C, and UART. Operating at a voltage range of 2.2 to 3.6 volts, the ESP32 is also optimized for low power consumption in idle mode. Thanks to its compatibility with the Arduino development environment, it offers easy programming and flexible development for a wide array of smart and automated control applications.

III.2.4.4.M-F wire (male to female):

A Male-to-Female (M-F) jumper wire is used to connect electronic components, featuring a male pin on one end and a female socket on the other. These wires are flexible, easy to handle, and commonly used for building circuits with breadboards and microcontrollers like Arduino. They come in various lengths and colors, which helps organize wiring and makes it easier to identify connections during prototyping or circuit assembly.

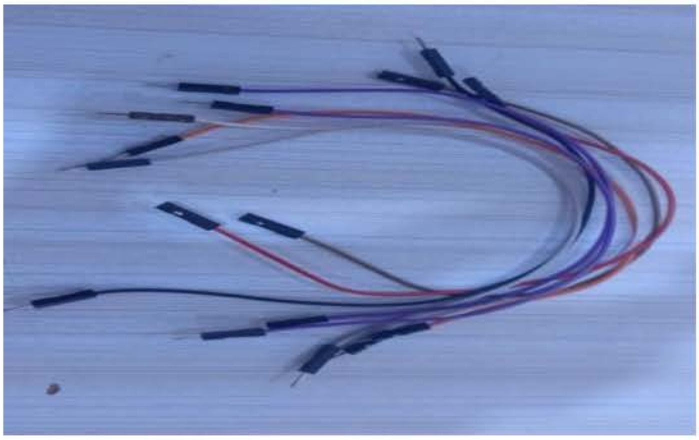


Fig-III.10: M-F wire (male to female).

III.2.4.5. Plug Panel:

The Arduino plug board, commonly known as a breadboard, is a tool used to build and test electronic circuits without the need for soldering. Its grid of slots allows components and wires to be inserted easily and quickly, making it an ideal solution for prototyping and experimenting with circuit designs.

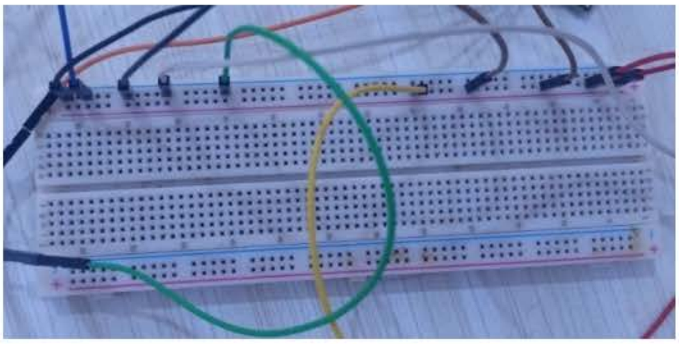


Fig-III.11: Plug Panel.

III.3. working principle:

III.3.1. Tools and materials PCM used:

Paraffin:

Paraffin is a soft, white or colorless solid, derived from coal, petroleum, or oil shale. Its properties include a melting point, which typically ranges between 46 and 68 degrees Celsius, which makes it easily melt when heated. It also has the ability to retain heat and release it slowly, but it is expensive.

Paraffin is used in a wide range of applications including home heating and heat storage.

Fig-III.12: Paraffin.

Aluminum filings:

Aluminum filings are small wastes, such as chips or shavings, that result from aluminum forming and manufacturing processes. They are recyclable and can also be used in other applications. They have excellent heat transfer properties and are inexpressive.

Fig-III.13: Aluminum filings.

Iron panels:

We used 8 iron bars, 1 m high, 6 cm long, 4 cm wide and 0.15 cm thick (neglected), closed at the bottom and with a stopper at the top.

Fig-III.14: Iron panels.

Repression:

An aluminum funnel was used to facilitate the process of pouring the mixture (paraffin and aluminum filings) into the panels.

Fig III.15: Repression.

Electronic scale:

We used an electronic scale to weigh both the paraffin and the aluminum filings.

Fig III.16: Electronic scale

- **We also used a stove, a gas cylinder, an aluminum pot, and an electric saw.**

Fig-III.17: stove, gas cylinder, aluminum pot, electric saw.

Thermometer:

This device is a multi-channel temperature data logger. Its primary function is to measure and record temperatures from 12 different input channels simultaneously, then store this data on an SD card for later reference and analysis.

Fig-III.18: Lutron 12 Channels Temperature Recorder BTM-4208SD

Air speed and volume measuring device:

This device is an anemometer with a data logger function. Its primary function is to measure airflow (wind) velocity and temperature simultaneously, and record this data onto an SD card for later analysis.

Fig-III.19: Lutron AM-4207SD Anemometer.

Preventive measures:

For our safety, we wore masks, heat-insulated gloves, and aprons.

III.3.2. Description of the Experimental Procedure:

First, a specific quantity of aluminum filings was weighed using a high-precision digital balance. As shown in Figure 1, the recorded mass was 0.082 kilograms.

Second, the required amount of paraffin was measured. A piece weighing 0.574 kilograms was placed on the same digital scale. This piece was then doubled, resulting in a total paraffin mass of 1.150 kilograms for the experiment.

Third, the weighed aluminum filings and the two paraffin pieces (with a combined weight of 1.150 kg) were prepared and arranged for the next phase of the procedure.

Fourth, both paraffin pieces were cut into small cubes to facilitate melting. These cubes were transferred into a metal pot and gently heated over a gas stove, as seen in the accompanying image.

Fifth, after about five minutes of heating, the paraffin began to melt. The image shows the start of this phase, where parts of the paraffin are transitioning from solid to a clear liquid.

Sixth, the melting process was completed following an additional three minutes of heating. The paraffin reached a temperature of approximately 75°C, resulting in a fully melted, clear, and uniform liquid.

Seventh, the previously weighed aluminum filings were gradually added to the molten paraffin while continuously stirring with a wooden stick. This step was essential to ensure the uniform dispersion of aluminum within the mixture.

Eighth, the homogeneous mixture of molten paraffin and aluminum filings was carefully poured into a hollow iron rod mold.

Ninth, the mold was gently shaken to eliminate any air pockets and to ensure that the aluminum filings were evenly distributed throughout the paraffin.

Tenth, the filled iron mold was placed on a stable surface to cool naturally at room temperature. During this stage, the paraffin solidified and adopted the shape of the rod.

Note: This 10-step procedure was repeated seven more times to produce a total of eight iron rods filled with the paraffin–aluminum mixture. The entire preparation process lasted approximately five and a half hours.

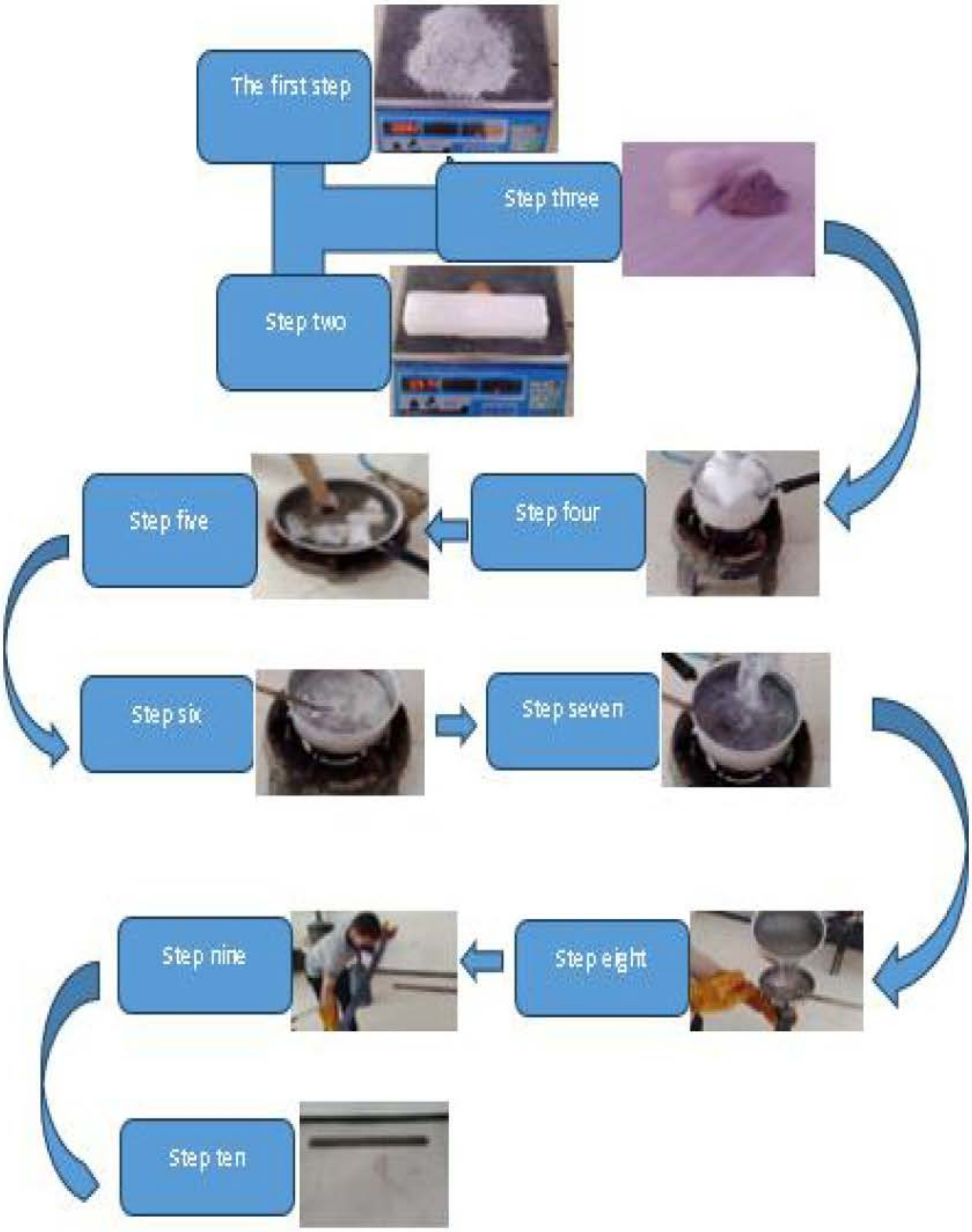


Fig.III-20: Diagram of the Different Steps of Experimental Protocol Preparation.

III.4. Results and discussions

To test the effectiveness of this system, a series of thermal measurements were conducted to evaluate the impact of PCM on system performance.

The temperatures and air velocities entering and exiting the barn were recorded to analyze performance and determine the optimal setting for the solar heating system. The following results display the measured temperature and air velocity data, allowing for accurate comparison of system performance under different operating conditions.

Table III.2: Measurement of the temperature

	T_1	T_2	T_3	T_4	T_5
10h:48	43.3°c	33.7°c	63.6°c	54.2°c	53.8°c
10h:58	44.7°c	38.4°c	62.4°c	52.4°c	37.0°c
11h:08	45.5°c	39.9°c	62.9°c	54.7°c	39.3°c
11h:18	46.7°c	39.8°c	64.0°c	55.0°c	38.7°c
11h:28	47.4°c	46.7°c	65.0°c	54.6°c	37.6°c
11h:38	47.9°c	41.1°c	63.3°c	53.2°c	39.5°c
11h:48	47.7°c	40.7°c	63.0°c	53.0°c	41.0°c
11h:58	48.2°c	43.1°c	64.4°c	53.3°c	38.6°c
12h:08	48.9°c	40.3°c	64.3°c	52.8°c	41.9°c
12h:18	49.3°c	40.1°c	64.5°c	53.9°c	41.2°c
12h:28	49.9°c	40.6°c	64.3°c	53.8°c	41.9°c
12h:38	50.1°c	44.6°c	65.4°c	55.2°c	39.9°c
12h:48	49.6°c	40.5°c	65.9°c	54.4°c	40.9°c
12h:58	50.1°c	41.3°c	65.1°c	53.9°c	42.1°c
13h:08	50.3°c	43.8°c	65.9°c	55.8°c	40.1°c
13h:28	51.1°c	41.2°c	65.7°c	55.5°c	41.6°c
13h:38	51.0°c	45.3°c	64.8°c	55.6°c	40.1°c
13h:48	51.1°c	41.9°c	64.1°c	54.3°c	42.7°c
13h:58	51.8°c	44.0°c	63.9°c	55.1°c	40.6°c
14h:08	51.3°c	42.5°c	62.4°c	52.6°c	43.1°c
14h:18	51.1°c	42.5°c	62.5°c	51.4°c	41.2°c
14h:28	50.9°c	40.4°c	61.0°c	51.1°c	43.6°c
14h:38	50.5°c	41.3°c	60.3°c	50.8°c	42.2°c
14h:48	50.4°c	40.5°c	59.5°c	50.4°c	42.3°c
14h:58	50.5°c	39.7°c	59.6°c	50.3°c	42.1°c
15h:08	50.1°c	40.3°c	58.2°c	49.7°c	41.6°c
15h:18	49.7°c	40.6°c	58.4°c	49.4°c	41.2°c
15h:28	49.4°c	40.7°c	56.7°c	47.9°c	40.9°c
15h:38	49.2°c	39.3°c	55.9°c	48.5°c	41.7°c
15h:48	48.7°c	39.6°c	54.7°c	46.6°c	40.0°c
15h:58	47.9°c	39.5°c	53.1°c	46.7°c	40.2°c
16h:08	47.7°c	39.4°c	52.7°c	45.5°c	39.1°c

Measurement point definitions for each test:

- T_1: Temperature inside the barn
- T_2: Incoming air temperature
- T_3: Temperature at the end of the solar panel
- T_4: Temperature at the center of the solar panel
- T_5: Temperature outside the barn
- V_1: Air velocity exiting the barn by fans
- V_2: Air velocity entering the barn

Table III.3: Velocity Measurement

	V_1	V_2
10h:48	3.1m/s	1.4 m/s
10h:58	3.1 m/s	1.4 m/s
11h:08	3.3 m/s	1.4 m/s
11h:18	3.5 m/s	1.2 m/s
11h:28	4.0 m/s	1.4 m/s
11h:38	3.8 m/s	1.2 m/s
11h:48	3.6 m/s	1.3 m/s
11h:58	2.6 m/s	1.2 m/s
12h:08	2.9 m/s	1.4 m/s
12h:18	3.7 m/s	1.3 m/s
12h:28	2.4 m/s	1.2 m/s
12h:38	2.6 m/s	1.4 m/s
12h:48	4.1 m/s	1.9 m/s
12h:58	2.9 m/s	1.4 m/s
13h:08	4.5 m/s	1.4 m/s
13h:28	3.2m/s	1.4 m/s
13h:38	3.4 m/s	1.2 m/s
13h:48	4.1 m/s	1.5 m/s
13h:58	4.1 m/s	1.5 m/s
14h:08	3.0 m/s	1.5 m/s
14h:18	4.6 m/s	1.7 m/s
14h:28	3.8 m/s	1.3 m/s
14h:38	4.3 m/s	1.4 m/s
14h:48	4.0 m/s	1.3 m/s
14h:58	4.5 m/s	1.2 m/s
15h:08	4.1 m/s	1.4 m/s
15h:18	4.2 m/s	1.3 m/s
15h:28	3.2 m/s	1.5 m/s
15h:38	3.3 m/s	1.4 m/s
15h:48	2.2 m/s	1.5 m/s
15h:58	3.9 m/s	1.4 m/s
16h:08	2.9 m/s	1.4 m/s

Figure III.21 illustrates the variation in solar radiation flux and ambient temperature recorded throughout the day of May 19, 2025, from approximately 8:30 AM to 2:30 PM. As shown in the figure, the solar radiation flux increases markedly during the morning hours, beginning at approximately 550 W/m² at 8:30 AM and reaching a peak value of nearly 1000 W/m² around 12:00 PM. A relatively stable plateau is observed between 11:30 AM and 1:00 PM, during which the radiation remains close to its maximum level. After 1:00 PM, the solar radiation declines sharply, dropping to approximately 650 W/m² by 2:30 PM. This diurnal pattern reflects typical clear-sky solar radiation behavior, primarily governed by the sun's elevation angle.

Regarding the right-hand axis of the figure, the ambient temperature starts the day at around 36°C and exhibits a gradual increase as solar radiation intensifies. The temperature rises to a range between 40°C and 42°C by late morning and early afternoon. Minor fluctuations are observed around 12:00 PM, which may be attributed to short-term environmental changes such as wind gusts

General Conclusion

The experimental investigation presented in this thesis demonstrates the significant potential of integrating Phase Change Materials (PCM) with solar heating systems to enhance thermal comfort in poultry houses. The study focused on evaluating the performance of a prototype poultry house equipped with a PCM-enhanced solar air collector, measuring key parameters such as temperature, humidity, and air velocity under real-world conditions.

The results revealed that the PCM-based system effectively absorbed and stored solar energy, maintaining indoor temperatures consistently higher than ambient levels by 5 to 11°C. This thermal stability is critical for poultry welfare, as it mitigates the adverse effects of external temperature fluctuations. The solar collector, incorporating black-coated iron panels and paraffin-aluminum PCM, achieved peak surface temperatures of up to 66°C, highlighting its efficiency in capturing and retaining heat. Additionally, the system exhibited thermal inertia, delaying temperature peaks and ensuring prolonged heat release, which is particularly advantageous during periods of declining solar radiation.

The integration of fans further optimized air circulation, ensuring uniform heat distribution and improving overall system performance. These findings underscore the viability of solar-PCM hybrid systems as a sustainable and energy-efficient alternative to traditional heating methods, especially in regions with abundant solar resources.

In summary, this research contributes to the advancement of renewable energy solutions in poultry farming by addressing the dual challenges of energy efficiency and environmental sustainability. Future studies could explore the scalability of this system, its economic feasibility, and its adaptability to varying climatic conditions to further validate its practical application in the poultry industry. The outcomes of this work pave the way for broader adoption of innovative heating technologies, ultimately supporting the global transition toward greener agricultural practices.

References

References

[1] Ernest F. Bazen , Matthew A. Brown , Feasibility of solar technology (photovoltaic) adoption: A case study on Tennessee’s poultry industry , Renewable Energy 34 (2009) 748–754. https://doi.org/10.1016/j.renene.2008.04.003

[2] Marcelo Bastos Cordeiro, Ilda de Fátima Ferreira Tinôco, Jadir Nogueira da Silva, Ricardo Brauer Vigoderis, Francisco de Assis de Carvalho Pinto, Paulo Roberto Cecon , Thermal comfort and performance of chicks submitted to different heating systems during winter, R. Bras. Zootec. 39 (1) • Jan 2010. https://doi.org/10.1590/S1516-35982010000100029

[3]E. Mirzaee-Ghaleh, M. Omid, A. Keyhani , M.J. Dalvand **,** Comparison of fuzzy and on/off controllers for winter season indoor climate management in a model poultry house. Computers and Electronics in Agriculture 110 (2015) 187–195. http://dx.doi.org/10.1016/j.compag.2014.11.017

[4] Fawaz, H., Obiad, M. G., Ghaddar, N., & Ghali, K. (2014). Solar-assisted localized ventilation system for poultry brooding. Energy and Buildings, 71, 142–151. [1] https://doi.org/10.1016/j.enbuild.2013.12.021

[5] Kyeong-seok Kwon , In-bok Lee, G. Qiang Zhang, Taehwan Ha , Computational fluid dynamics analysis of the thermal distribution of animal occupied zones using the jet-drop-distance concept in a mechanically ventilated broiler house. http://dx.doi.org/10.1016/j.biosystemseng.2015.05.008

[6]G. Zhou , M. Pang , Experimental investigations on the performance of a collector–storage wall system using phase change materials . Energy. Conver. Manag 105 (2015) 178–188 . https://doi.org/10.1016/j.enconman.2015.07.070

[7] Rojano, F., Bournet, P.-E., Hassouna, M., Robin, P., Kacira, M., & Choi, C. Y. (2015). Modelling heat and mass transfer of a broiler house using computational fluid dynamics. Biosystems Engineering, 136, 1–13. https://doi.org/10.1016/j.biosystemseng.2015.05.004

[8] Kapica, J., Pawlak, H., & Ścibisz, M. (2015). Carbon dioxide emission reduction by heating poultry houses from renewable energy sources in Central Europe. Renewable Energy, 83, 1147-1154.https://doi.org/10.1016/j.physa.2014.03.034

[9] Shaun Smith , Joseph Meade , James Gibbons , Kevina McGill , Declan Bolton , Paul Whyte, Impact of direct and indirect heating systems in broiler units on environmental

conditions and flock performance , Journal of Integrative Agriculture 2016, 15(11): 2588–2595. https://doi.org/10.1016/S2095-3119(16)61380-1

[10] Andrea Costantino , Enrico Fabrizio, Andrea Ghiggini , Mauro Bariani , Climate control in broiler houses: A thermal model for the calculation of the energy use and indoor environmental conditions, Energy & Buildings 169 (2018) 110–126. https://doi.org/10.1016/j.enbuild.2018.03.056

[11]M .S. Yousef, H. Hassan, Energetic and exergetic performance assessment of the inclusion of phase change materials (PCM) in a solar distillation system . Energy. Conver. Manag 179 (2019) 349–3. https://doi.org/10.1016/j.enconman.2018.10.078

[12]. Wei Chen . Wei li . (2019). Numerical analysis on the thermal performance of a novel PCM-encapsulated porous heat storage Trombe-wall system. Solar Energy. https://doi.org/10.1016/j.solener.2019.06.052

[13]. Al Siyabi, I, Khanna, S, Mallick, T., & Sundaram, S. (2019). An experimental and numerical study on the effect of inclination angle of phase change materials thermal energy storage system. Journal of Energy Storage, 23, 57-68.

https://doi.org/10.1016/j.est.2019.03.010

[14]. Bilardo, M., Fraisse, G., Pailha, M., & Fabrizio, E. (2019). Modelling and performance analysis of a new concept of integral collector storage (ICS) with phase change material

https://doi.org/10.1016/j.solener.2019.03.032

[15]. Ojike, O., & Okonkwo, W. I. (2019). Study of a passive solar air heater using palm oil and paraffin as storage media. Case Studies in Thermal Engineering, 14, 100454.

https://doi.org/10.1016/j.csite.2019.100454

M . Bilardob , G. Fraissea , M. Pailhaa , E. Fabrizio , Design and

experimental analysis of an Integral Collector Storage (ICS) prototype for DHW production . App. Energy 259 (2020) 11410 . https://doi.org/10.1016/j.apenergy.2019.114104

[17]. Stropnik, R., Koželj , R , Zavrl , E , & Stritih, U. (2019). Improved thermal energy storage for nearly zero energy buildings with PCM integration . *Solar Energy*, *190*, 420-426.

https://doi.org/10.1016/j.solener.2019.08.041

[18]. Aly, Kareem A., Ahmed R. El-Lathy, and Mahmoud A. Fouad . "Enhancement of solidification rate of latent heat thermal energy storage using corrugated fins." *Journal of Energy Storage* 24 (2019): 100785. https://doi.org/10.1016/j.est.2019.100785.

[19]J. Izar-Tenorio , P. Jaramillo , W. M. Griffin , M. Small , Impacts of projected climate change scenarios on heating and cooling demand for industrial broiler chicken farming in the Eastern U.S . Journal of Cleaner Production 255 (2020) 120306 . https://doi.org/10.1016/j.jclepro.2020.120306

[20]. Mahood, H. B., Mahdi, M. S., Monjezi, A. A., Khadom, A. A., & Campbell, A. N. (2020). Numerical investigation on the effect of fin design on the melting of phase change material in a horizontal shell and tube thermal energy storage. *Journal of Energy Storage*, *28*, 101234

https://doi.org/10.1016/j.est.2020.101331

[21]. Uzodinma, E. O., Ojike, O., Etoamaihe, U. J., & Okonkwo, W. I. (2020). Performance study of a solar poultry egg incubator with phase change heat storage subsystem. *Case Studies in Thermal* [1] *Engineering*, *22*, 100593.

https://doi.org/10.1016/j.csite.2020.100593

[22]. Vikas A. Yadav, Mahesh Kumar Yadav, وآخرون. "Phase change materials for comfort management of poultry farms - A review". Materials Today: Proceedings, (2021).

https://doi.org/10.1016/j.matpr.2021.09.152.

[23]. Leandra Vanbaelinghem , Andrea Costantino , Florian Grassauer 1 and Nathan Pelletier

[24] Ma, H., Tu, Y., Yang, X., Yang, Z., & Liang, C. (2022). Influence of tunnel ventilation on the indoor thermal environment of a poultry building in winter. *Building and Environment*, *223*, 109448.

https://doi.org/10.1016/j.buildenv.2022.109448

[25]M. Fallah Najafabadi , M. Farhadi , H. T. Rostami , Numerically analysis of a Phase-change Material in concentric double-pipe helical coil with turbulent flow as thermal storage unit in solar water heaters . Journal of Energy Storage 55 (2022) 105712 . https://doi.org/10.1016/j.est.2022.105712

[26] Yousra Boutera, Nora Boultif, Amar Rouag, Charafeddine Beldjani & Noureddine Moummi , Performance of earth-air heat exchanger in cooling, heating, and reducing carbon

emissions of an industrial poultry farm: A case study , Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. https://doi.org/10.1080/15567036.2022.2132323

[27] Leandra Vanbaelinghem , Andrea Costantino , Florian Grassauer , Nathan Pelletier, Alternative Heating, Ventilation, and Air Conditioning (HVAC) System Considerations for Reducing Energy Use and Emissions in Egg Industries in Temperate and Continental Climates: A Systematic Review of Current Systems, Insights, and Future Directions, Sustainability 2024, 16, 4895. https://doi.org/10.3390/su16124895

[28] Choi, H. C., Salim, H. M., Akter, N., Na, J. C., Kang, H. K., Kim, M. J., ... & Suh, O. S. (2012). Effect of heating system using a geothermal heat pump on the production performance and housing environment of broiler chickens. *Poultry science*, *91*(2), 275-281. https://doi.org/10.3382/ps.2011-01666

[29] Martinopoulos, G., Papakostas, K. T., & Papadopoulos, A. M. (2018). A comparative review of heating systems in EU countries, based on efficiency and fuel cost. *Renewable and Sustainable Energy Reviews*, *90*, 687-699. https://doi.org/10.1016/j.rser.2018.03.060

[30] Poultry Hub. 2010. Climate in poultry houses. Accessed August 17, 2011. http://www.poultryhub.org/chicken-meat-industry/climate-in-poultry-houses

[31] Mahmoud, M., Ramadan, M., Naher, S., Pullen, K., & Olabi, A. G. (2021). The impacts of different heating systems on the environment: A review. *Science of The Total Environment*, *766*, 142625. https://doi.org/10.1016/j.scitotenv.2020.142625

[32] Kerimray, A., Rojas-Solórzano, L., Torkmahalleh, M. A., Hopke, P. K., & Gallachóir, B. P. Ó. (2017). Coal use for residential heating: patterns, health implications and lessons learned. *Energy for Sustainable Development*, *40*, 19-30. https://doi.org/10.1016/j.esd.2017.05.005

[33] Honicky, R. E., & Osborne 3rd, J. S. (1991). Respiratory effects of wood heat: clinical observations and epidemiologic assessment. *Environmental health perspectives*, *95*, 105-109.https://doi.org/10.1289/ehp.9195105

[34] Maker, T. M. (2004). Wood-chip heating systems. *A guide for institutional and commercial biomass installations*, 1-93. https://www.canr.msu.edu/uploads/resources/pdfs/Wood-Chip-Heating-Guide.pdf

[35] Lasek, J. A., Matuszek, K., Hrycko, P., & Piechaczek, M. (2018). Adaptation of hard coal with high sinterability for solid fuel boilers in residential heating systems. *Fuel*, *215*, 239-248. https://doi.org/10.1016/j.fuel.2017.11.020

[36] Onifade, M., & Genc, B. (2020). A review of research on spontaneous combustion of coal. *International Journal of Mining Science and Technology*, *30*(3), 303-311.https://doi.org/10.1016/j.ijmst.2020.03.001

[37] Zhang, J., & Smith, K. R. (2007). Household Air Pollution from Coal and Biomass Fuels in China: Measurements, Health Impacts, and Interventions. *Environmental Health Perspectives*, *115*(6), 848–855. http://www.jstor.org/stable/4139302

[38] Křůmal, K., Mikuška, P., Horák, J., Hopan, F., & Kuboňová, L. (2021). Influence of boiler output and type on gaseous and particulate emissions from the combustion of coal for residential heating. *Chemosphere*, *278*, 130402. https://doi.org/10.1016/j.chemosphere.2021.130402

[39] Křůmal, K., Mikuška, P., Horák, J., Hopan, F., & Krpec, K. (2019). Comparison of emissions of gaseous and particulate pollutants from the combustion of biomass and coal in modern and old-type boilers used for residential heating in the Czech Republic, Central Europe. *Chemosphere*, *229*, 51-59. https://doi.org/10.1016/j.chemosphere.2019.04.137

[40] Dr. Tamim Shahna. Book: Because Winter is at the Door, page (165-190). https://www.poultryworld11.com/2022/01/1_26.html

[41] Soliman, E. S., Ali, A. A., & Gafaar, R. E. M. (2021). Impact of heating systems on air and litter quality in broiler houses, performance, behavior, and immunity in broiler chickens. *Adv. Anim. Vet. Sci*, *9*(2), 301-314.https://www.researcherslinks.com/nexus_uploads/files/AAVS_9_2_301-314.pdf

[42] Caracci, E., Canale, L., Buonanno, G., & Stabile, L. (2022). Sub-micron particle number emission from residential heating systems: A comparison between conventional and condensing boilers fueled by natural gas and liquid petroleum gas, and pellet stoves. *Science of The Total Environment*, *827*, 154288.https://doi.org/10.1016/j.scitotenv.2022.154288

[43] Alaneme, K. K., & Olanrewaju, S. O. (2010). Design of a Diesel fired Heat-treatment Furnace. *Journal of Minerals & Materials Characterization & Engineering*, *9*(7), 581-591. https://www.scirp.org/pdf/jmmce20100700001_54539239.pdf

[44] Léger, J., Rousse, D. R., Le Borgne, K., & Lassue, S. (2018). Comparing electric heating systems at equal thermal comfort: An experimental investigation. *Building and Environment*, *128*, 161-169. https://doi.org/10.1016/j.buildenv.2017.11.035

[45] Moon, B. E., Lee, M. H., Kim, H. T., Choi, T. H., Kim, Y. B., Ryou, Y. S., & Kim, H. T. (2017). Evaluation of thermal performance through development of an unglazed transpired collector control system in experimental pig barns. *Solar Energy*, *157*, 201-215. https://doi.org/10.1016/j.solener.2017.08.026

[46] Leonard, S. M., Xin, H., Brown-Brandl, T. M., Ramirez, B. C., Johnson, A. K., Dutta, S., & Rohrer, G. A. (2021). Effects of farrowing stall layout and number of heat lamps on sow and piglet behavior. *Applied Animal Behaviour Science*, *239*, 105334. https://doi.org/10.1016/j.applanim.2021.105334

[47] Salih, A. M., & Ahmed, A. R. M. (2016). The effect of magnetic field on the boiler performance fueled with diesel. *International Journal of Scientific & Engineering Research*, *7*(2), 406-410. https://www.researchgate.net/profile/Adel-Salih/publication/296549852_The_effect_of_magnetic_field_on_the_boiler_performance_fueled_with_diesel/links/56d68a7408aebabdb4005e81/The-effect-of-magnetic-field-on-the-boiler-performance-fueled-with-diesel.pdf

[48] Debbi, S., Elisa, P., Nigel, B., Dan, P., & Eva, R. (2014). Factors influencing household uptake of improved solid fuel stoves in low-and middle-income countries: a qualitative systematic review. *International journal of environmental research and public health*, *11*(8), 8228-8250. https://doi.org/10.3390/ijerph110808228

[49] Khiraiya, K., Ramana, P. V., Panchal, H., Sadasivuni, K. K., Doranehgard, M. H., & Khalid, M. (2021). Diesel-fired boiler performance and emissions measurements using a combination of diesel and palm biodiesel. *Case Studies in Thermal Engineering*, *27*, 101324. https://doi.org/10.1016/j.csite.2021.101324

[50] Krishna, C. R. (2001). *BIODIESEL BLENDS IN SPACE HEATING EQUIPMENT* (No. BNL-68852). Brookhaven National Lab.(BNL), Upton, NY (United States). https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=82139708e464a7856ce7053cac7679807a46168f

[51] Wathes, S. M., Christensen, H. H., Aarts, J. M., and Berckmans, D. (2013). Poultry House Environment: A Review. Biosystems Engineering, 115(4), 370-388.

[52] Yuanlong Cui, Elmer Theo, Togba Gurler, Yuhong Su, Rifat Safa, "Feasibility of Implementing a Renewable Hybrid Heating System in Poultry Houses: A Case Study in the

East Midlands, UK," International Journal of Low Carbon Technologies, Volume 16, Issue 1, March 2021, Pages 73–88,

https://doi.org/10.1093/ijlct/ctaa037

[53] W. Turkenburg, Renewable Energy Officer, The Netherlands: Utrecht University

[54] «RENEWABLES Biomass Energy and Waste-To-Power: Energy From Waste,» Stellaractive, 06 01 2023. [En ligne]. Available: **https://powerzone.clarkpublicutilities** .com/learn-about-renewable-energy/biomass-energy/. [Accès le 31 05 2023].

[55].Cui, Y., Theo, W. L., Gurler, T., Su, Y., & Saffa, R. (2020). A comprehensive review on renewable and sustainable heating systems for poultry farming. International Journal of Low-Carbon Technologies, 15(1), 121-142.

https://doi.org/10.1093/ijlct/ctz048

[56]. M. A. HACHMI, Exploitation and computer programming of documents

[57] Ahmed Moussa Mahmoud, "New and Renewable Energy in Egypt: From a Geographical Perspective," Minya University, Department of Geography

[58] Regular techniques related to thermal depletion of ventilation of buildings, Boumardas: University M'hamed Bougara, Boumerdes, 2011

[59]. Turzyński, T., Kluska, J., & Kardaś, D. (2022). Study on chicken manure combustion and heat production in terms of thermal self-sufficiency of a poultry farm. Renewable Energy, 191, 84-91.

https://doi.org/10.1016/j.renene.2022.04.034

[60]. Elasri, O., & Afilal, M.E. (2016). Potential for biogas production from the anaerobic digestion of chicken droppings in Morocco. International Journal of Recycling of Organic Waste in Agriculture, 5(3), 195-204. DOI: 10.1007/s40093-016-0128-4.

https://link.springer.com/article

[61].Ismail Masalha, Mutaz Elayyan, Husam Aldean Bani Issa. (2017). Use of Biogas Energy in Poultry Farming Heating. The International Journal of Engineering and Science (IJES), Volume 6, Issue 3, Pages 58-63. DOI: 10.9790/1813-0603025863.

https://www.researchgate.net/publication/315954554

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

[63]. Al-Busoul, M., & Elayyan, M. (2014). Utilization of geothermal energy in poultry farming. Journal of Energy Technologies and Policy, 4(10), 25-34. Retrieved from http://www.iiste.org

[64]. Heating poultry houses from renewable energy sources in Central Europe. Agric Syst

2015;139:238–49.

[65].L. Cristiano, Use of infrared-based devices in aesthetic medicine and for beauty and wellness treatments, Infrared Physics & Technology, Volume 102, 2019, 102991, ISSN 1350-4495,

https://doi.org/10.1016/j.infrared.2019.102991.

[66].Pescatore, A.J., & Jacobs, J. (2014). Poultry Production Manual. College of Agriculture, Food and Environment. University of Kentucky Extension. Lexington, KY.

http://www2.ca.uky.edu/poultryprofitability/production_manual.html

[67]. Xiangguo Xu, Ziwen Zhong, Shiming Ding, Xiaobo Zhang, "A Review of Temperature and Humidity Control Methods with Focus on Air Conditioning Equipment and Control Algorithms Applied to Small and Medium-Sized Buildings," Journal of Energy and Buildings, Vol. 162, 2018, pp. 163–176, ISSN 0378-7788, https://doi.org/10.1016/j.enbuild.2017.12.038.

[68] Zakia Afroz, J.M. Shafiullah, Tania Orme, Gary Higgins, Modeling techniques used in building heating, ventilation and air conditioning control systems: A review, Renewable and Sustainable Energy Reviews, Vol. 83, 2018, pp. 64-84, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2017.10.044.

[69]. Dincer, I., & Rosen, M. A. (2011). Thermal energy storage: systems and applications. John Wiley & Sons.

[70]. Vinil Desai, Jenny Sonku Prasad, P. Muthukumar, M. Mustafa Rahman, Thermochemical Energy Storage Systems for Cooling and Heating Applications: A Review, Energy Conversion and Management, Vol. 229, 2021, 113617, ISSN 0196-8904, https://doi.org/10.1016/j.enconman.2020.113617.

[71]. Yao Zhao, Changing Zhao, Tao Wen, Christos N. Markides. (2022). Sensitive High-Temperature Storage - Industrial Applications. In Luisa F. Cabeza (ed.), Encyclopedia of Energy Storage (pp. 424–432). Elsevier.

https://doi.org/10.1016/B978-0-12-819723-3.00070-6

[72]. Shaofei Wu, Ting Yan, Zihan Kuai, and Weiguo Pan. (2020). Improving the thermal conductivity of phase change materials for thermal energy storage: A review. Energy Storage Materials, 25, 251–295.

https://doi.org/10.1016/j.ensm.2019.10.010

[73] .S. OUARET, Conception d’un système de climatisation pour un poulailler, TIZI-OUZOU: Université Mouloud MAMMERI, Tizi-Ouzou, 2020.