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Design and Analysis of Ventilation System for Closed Poultry House in Tropical Climate Conditions

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ABSTRACT

The climate significantly impacts the temperature in different parts of the world. A moderate environment makes it simple to construct a chicken farm. Nevertheless, raising the birds in tropical places where typical temperatures can exceed 40-45°C is difficult because they can only survive at temperatures between 30°C and 35°C. As a result, the current study aimed to design a chicken house with a ventilation and cooling system to prevent excessive heat. The effectiveness of ventilation systems in maintaining liveable and constant conditions at the chicken house was assessed using computational fluid dynamics modeling to mimic internal and external airflows. In this study, a water evaporator-based cooling system and an exhaust fan-based ventilation system were built within a poultry house. ANSYS CFD was utilized to create the design and examine the flow of the model. The findings of each model were generated individually, and these results were compared to those of the other models to determine which model could decrease the temperature within the chicken coop. The proposed model's maximum temperature was around 30-32°C. A poultry house can be constructed using this idea to maintain chickens at a suitable temperature range of 30-32°C.

Keywords: Computational fluid dynamic, Evaporator, Exhaust fan, Poultry house, Ventilation

INTRODUCTION

Poultry is one of the agricultural sectors driving the fastest growth in the Indian economy. Crop output has grown at a rate of 1.5-2% per year, whereas egg and poultry meat production has grown at a rate of 8-10% per year (Mondal and Mishra, 2022). According to FAOSTAT data, India holds the sixth position in the global chicken market. The domestic poultry industry is currently experiencing exceptional growth, boasting a remarkable 18% growth rate. Moreover, investments in the production of chicken meat, which happens to be India's most popular meat, have seen substantial increases in this sector (Reddy and Bhatia, 2022). The annual broiler meat production in India is estimated to be 4.8 million tons. The broiler and egg industries in India generate $12.96 billion in income per year (Saner and Shekhawat, 2022). The number of eggs produced climbed from 30 billion in 2000 to 65 billion in 2014, while annual per capita egg consumption increased from 28 to 65, transforming India into one of the world's largest chicken markets (Das and Samanta, 2021). In India, more than 87% of chicken farms have double-winch curtained side vent apertures for natural ventilation; only circulating fans are used in the summer (Thapa, 2022). They struggle to maintain environmental controls, including appropriateness, stability, and uniformity of the interior climate, due to their inadequate ventilation systems, which causes significant stress on the hens, subpar disease control, and lower productivity (Guo et al., 2022). The broiler houses have been updated, but because of their expanded size to facilitate automation and high production, their interior temperature has not yet risen considerably (Costantino et al., 2022).

In various common types of broiler houses in India, previous studies have examined air temperature, relative humidity, gas concentrations, chicken weight, sudden death syndrome, mortality rates, and other factors (Ahmad et al., 2022). Many researchers performed field investigations in India to learn how ventilation affects the climate within broiler houses. Only a few measurement sites were located within the home, and these trials only

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lasted one season (Choab et al., 2019; Chimankare et al., 2023). Therefore, using their data to evaluate the reliability, stability, and appropriateness of the inner environment would be difficult. They also failed to submit a new ventilation plan. To meet India's three unique seasons, broiler house ventilation systems must be quickly modified. The fundamental problem with most field experiments was that the weather was frequently unexpected and variable, making it hard to affect it (Sanz et al., 2021). Computational fluid dynamics is one of the best and most efficient tools for analyzing agricultural aerodynamics (CFD, Han et al., 2021). It is typically the most straightforward, affordable, and precise method to assist design choices that take into account all of the nuances of an actual fluid flow. It offers trustworthy information and is applicable to early design cycles (Vinuesa and Brunton, 2022). However, the skill, knowledge, and experience of the designer have a big impact on CFD accuracy. More relevant and reliable data are needed to evaluate CFD validation and determine whether the problem's physics has been appropriately defined due to the growing quantity and quality of numerical simulations of flow fields (Gan et al., 2022).

In an effort to enhance and optimize the thermal well-being of broilers in current facilities, this study makes an effort to explain the air temperature and airflow patterns within a broiler house heated by an industrial metal furnace.

MATERIALS AND METHODS

A thorough explanation of the design's parameters and component elements is presented in this section. Four CFD models were simulated using FLUENT v19.1, a commercial software program. Based on the work by Xiao et al. (2022), the classic k-turbulence model with improved wall functions was used to create CFD models.

Poultry house design

The chicken coop was created as a component of a closed system. Brick walls, concrete floors, zinc-coated sheet metal, and mechanical ventilation and cooling systems were used to construct modern poultry houses. A total of 7500 birds can fit within the poultry house, which is 45.72 meters long, 9.14 meters wide, 4.57 meters high, 0.60 meters overhung, and has a roof with a 25% slope. On average, there were 17 birds per square meter. In the current study, chickens were kept on a litter floor. Both the foundation and the floor were constructed out of concrete. Figure 1 depicts a schematic of the poultry house.

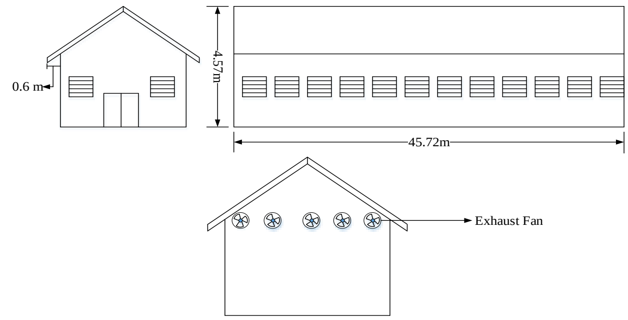

Figure 1. Schematics of poultry house

Window design with shutter

To promote airflow, windows were constructed on either side of the hen house. To guarantee adequate air circulation, 11 windows were constructed on each side of the poultry house by the design of the current idea. Maintaining the temperature within the ideal range of 32°C to 35°C is crucial for the effectiveness of the ventilation systems in providing the best air supply for the chickens inside the building. To achieve this, the design of the current model incorporates a window with a movable shutter. This adjustable shutter is a vital component as it allows for precise control over the amount of air entering the poultry house. As a result, it is crucial to keep the window shutter at a particular angle. The research results on the window ventilation system by Tao et al. (2021) showed that the outlet louvers could significantly influence temperature. The optimal louver angle of 45^{o} can increase natural airflow for two types of glazing by 10 to 14%, improving ventilation, compared to a condition without louvers. On the other hand, downward-opening louvers (112.5-1500) would lessen the natural flow by 6% to 9% for every 100-degree increase in louver angle. To measure the impact of typical solar conditions on the efficiency of natural ventilation, empirical models were also built. Figure 2 illustrates the window with ventilation schematics.

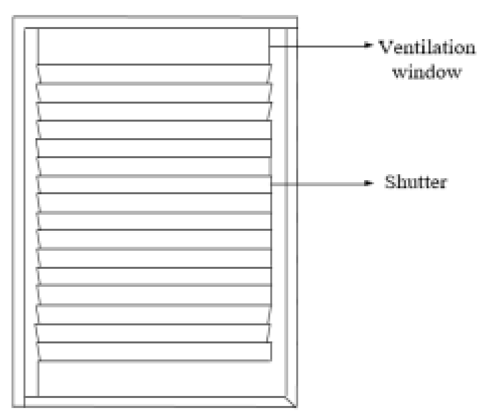

Figure 2. Ventilation window with shutter for poultry farm

Water sprinkler

The roof of the chicken house was made of zinc-coated sheet metal because the birds would be exposed to the sun's heat. Inside of the house was kept from heating up by direct evaporative cooling systems. A homogenous misting technique was applied at roof height, with a mist evaporation ratio of 0.33, a misting flow rate of 0.04 to 0.06 kilogram per second, and water output of 2.40-3.60 liters per minute. The water sprinkler's schematics are shown in Figure 3.

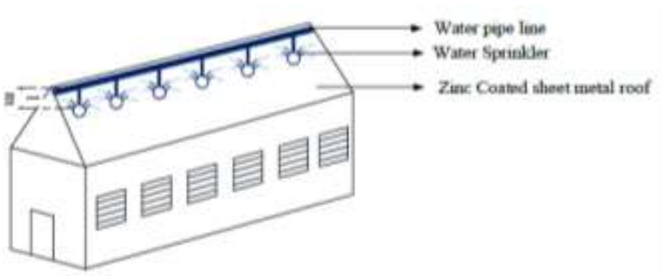

Figure 3. Schematics of water sprinkler for poultry farm

Exhaust fan for ventilation

The chicken's body temperature and the structure's interior warming up due to the climatic conditions contributed to the heating process. To evacuate the warm air from the poultry house, a ventilation system with an exhaust fan must be used. The ventilation system for the negative pressure tunnel in the current design consisted of five exhaust fans. The chicken house was equipped with an exhaust fan system to circulate the inside air outdoors. The fan was fixed inside the home on a side wall. Each fan had a 100 cfm (cubic feet per minute) output capacity. When the fan was running, the shutters were maintained open, and gravity drew them shut when it was not. The exhaust fan schematics for the ventilation system are presented in Figure 4.

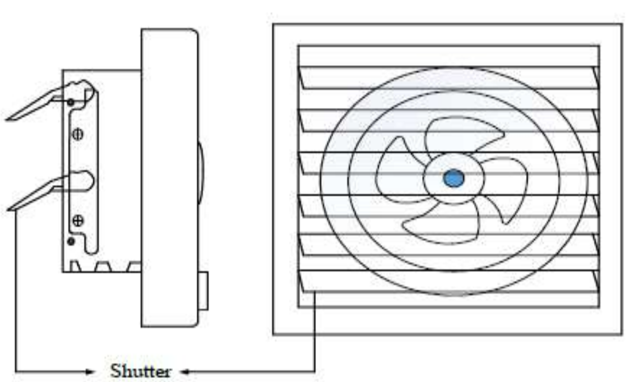

Figure 4. Schematics for exhaust fan in the poultry house

Computation fluid dynamics design evaluation

In this part, the thermal behavior of a chicken coop was explored using computational methods and fluid dynamics (CFD) data structures. Complex issues needed fast supercomputers, and software was created to increase accuracy and speed in difficult modeling situations. Initial validation typically entailed experimental methods, such as wind tunnels, and comparisons with prior research were made. The ANSYS CFD tool was used to simulate the flow.

Geometry

After starting ANSYS CFD, the model's geometry was created. To put the design into practice, there were two methods. To design using building parameters in ANSYS CFD, the model was first created in design software (SolidWorks, CATIA), imported into ANSYS, and then exported. ANSYS CFD was used to create the model. The design geometry schematic is shown in Figure 5.

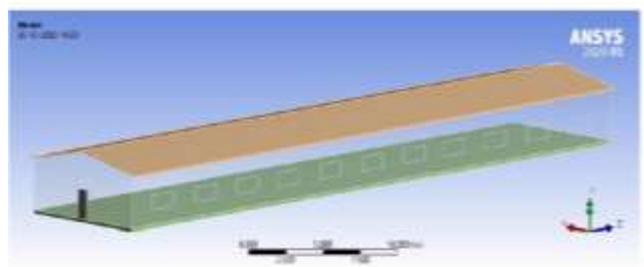

Figure 5. The geometry of poultry house in CFD

Meshing

Meshing the design was part of the second analytical step after the geometry generation stage. Similar to finite element simulations, a fluid body and its boundary were applied to a numerical grid in CFD meshing. For the current model, 691017 elements and 174741 nodes were mesh. A schematic illustration of the meshing is illustrated in Figure 6.

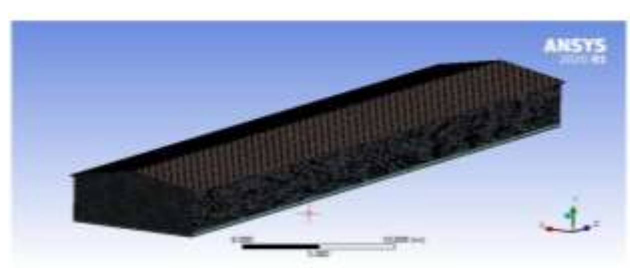

Figure 6. Schematics of the meshed design for poultry house

Setup

It is the third stage of the model's flow analysis. The model was built up using the appropriate domain (solid or fluid) choices. The inlet, outlet, roof, floor, and exhaust fan material qualities and processing parameters were set for each domain. The type of consequence has been demonstrated in this section. For the current model, two configurations that contain the Navier strokes equation and the continuity equation were activated.

Continuity equation

According to the continuity equation in fluid dynamics, the rate at which mass enters and leaves a system is the same as any steady-state process (Alabdalah et al., 2020). The continuity equation's differential form follows Formula 1.

$$\frac{\partial \rho}{\partial t} + \nabla (\rho u) = 0 \quad (1)$$

Where, t is time, ρ denotes fluid density, and u signifies flow velocity vector field.

Navier strokes equation

The Navier strokes equations, partial differential equations, were used in fluid mechanics to explain the movement of viscous fluids. These equations are advanced versions of those created in the eighteenth century by Leonhard Euler to explain the flow of incompressible and frictionless fluids. Mathematically speaking, the Cauchy momentum equation may be separated from the Navier-Stokes momentum equation. The Formula 2 shows primary convective pattern.

$$\frac{Du}{Dt} = \frac{1}{\rho} \nabla \cdot \sigma + g \quad (2)$$

The Cauchy momentum equation is obtained by multiplying a pressure value by the volumetric stress (Formula 3), which is the deviator stress term in the Cauchy stress tensor.

$$\rho \frac{Du}{Dt} = - \nabla p + \nabla \tau + \rho g \quad (3)$$

Where, ρ determines density, u refers to flow velocity, ▽ is divergence, p refers to pressure, t denotes time, and τ accounts for the deviator stress tensor.

Solution

In the fourth stage of the analysis process, the iteration was set to yield the most accurate result based on the setup details. The current design model had a 200-iteration cap, and the final calculation run was performed. Figure 7 explains the setup and solution's design.

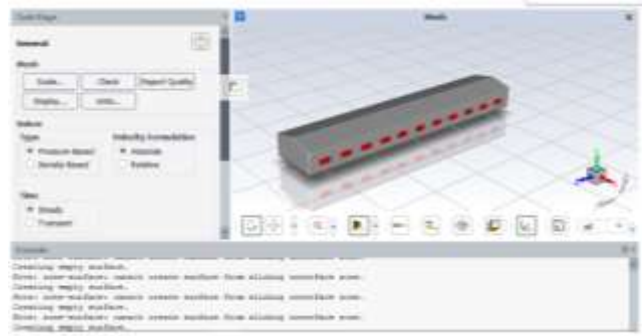

Figure 7. Setup and solution for poultry house

RESULTS AND DISCUSSION

The outcome was produced using four stages. There are four types of chicken houses, namely poultry houses without an exhaust fan or vaporizer, poultry houses with an exhaust fan outlet but no vaporizer, and poultry houses with both an exhaust fan and a vaporizer. The CFD was used to calculate how the microclimate in a mechanically ventilated broiler house varied in space throughout the summer and winter in research by Küçüktopcu et al. (2022). To contrast the predicted results, actual data on temperature, relative humidity, and airspeed were gathered within the chicken farm. The study simulated alternative remedies for two problems, including winter stagnation zones and high summer temperatures, which may cause poultry heat stress. An evaporative cooling pad system might lower the temperature by around 3°C when the mean air temperature in the residence exceeded 25°C in the summer. To address the issue of hot and humid air buildup in stagnant areas of the poultry house during the winter, the installation of four 500-mm circulation fans spaced 20 meters apart could be a practical solution. These fans would help in improving airflow and eliminating the temperature and humidity variations within the chicken house. This study demonstrated how CFD may be effective in creating the best heating, cooling, and ventilation systems in chicken barns.

To create practical designs for functional indoor hen settings, Chen et al. (2021) assessed cage-free home ventilation systems. The interior conditions, particularly at the hen level, could be dependably managed within the survival temperature range, according to quantitative assessments of airflow, temperature, and pressure distribution contours. The hen house's ventilation rates inside four ventilation systems were at the higher end of the recommended ventilation range, another sign that the farm could be relied upon to maintain appropriate air quality during cold weather. This study highlighted the value of employing computational fluid dynamics modeling as a research tool to address issues with animal welfare in animal housing designs.

A study by Ferraz et al. (2022) set out to assess the climate inside a heated commercial broiler house. The proposed CFD model rendered accurate simulations of the experimental data. This investigation discovered that numerous areas of the broiler house experienced heating system issues during the trial periods, which may have negatively impacted the comfort of the birds and, eventually, their productivity and monetary losses. The information gathered might be used as a guide for choosing the ideal setting to support the development of chicks.

In a cage-free hen house, Chen et al. (2021) investigated how successfully ventilation systems maintained constant and suitable living conditions for hens. Four full-scale, floor-raised hen coop CFD models in three dimensions were created. In addition to the conventional top-wall inlet sidewall exhaust (TISE) ventilation architecture, these models each represented one of three alternative ventilation systems. For each ventilation scheme, 2,365 individual birds were simulated using simple forms. The average airflow at the bird level of the standard TISE model was 0.35 m/s (69 ft/minutes), according to the simulation findings of the mid-wall inlet ridge exhaust and mid-wall inlet attic exhaust. Neither model considerably differed from this value.

The effectiveness of three passive cooling systems in meeting thermal and indoor air quality criteria in a semi-arid chicken barn was examined by Al Assaad et al. (2021). Direct evaporative cooling was 6.8% more expensive than using a dew-point evaporative cooler. Costs were decreased by 4.7% when customized ventilation was used instead of standard ventilation using dew point devices, simultaneously maintaining the same air quality and temperature.

According to Obando Vega et al. (2022), compost-bedded pack barns (CBP) needed sufficient ventilation and maintain stable temperatures to create the ideal environment for a good composting process. As a consequence, this study was carried out utilizing a compost barn construction model and dimensional analysis methods for naturally ventilated buildings. Using CFD, three-dimensional models of compost barns with different ridge patterns and wind directions were created, along with a visual depiction of how these factors influenced the airflow through the structure. The findings showed that the CFD model and simulations for barn ventilation matched the actual data and provided precise airflow forecasts via the design of the CBP barns for various roof ridge types. The findings also indicated that the open ridge with a chimney was the ideal roof design for a west-to-east wind direction in the winter.

Poultry house without exhaust fan and vaporizer

In this model, the intake and outlet at the exhausted home were just the windows, and the outcome was calculated. Figures 8 and 9 display the temperature and velocity results from ANSYS CFD.

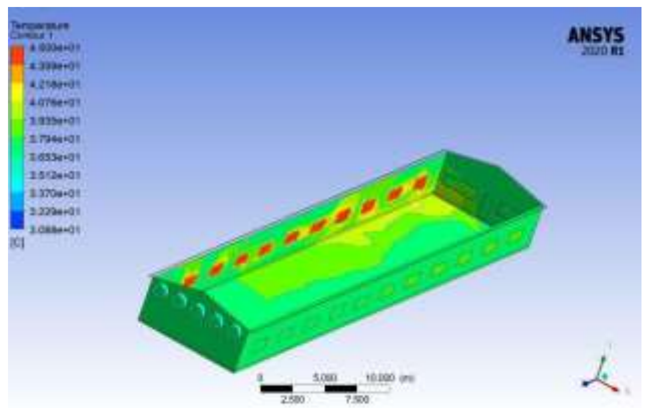

Figure 8. The temperature of the poultry house without using an exhaust fan and vaporizer

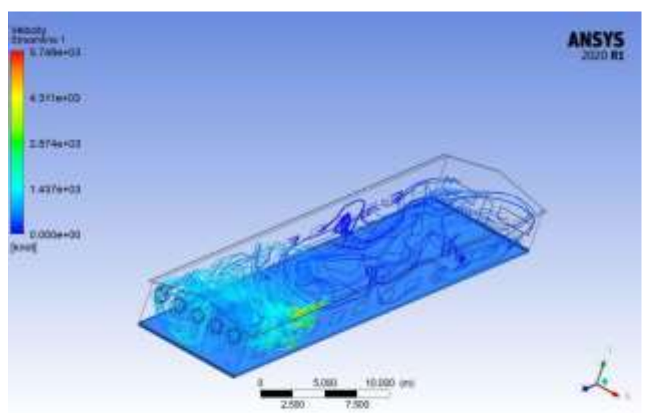

Figure 9. Velocity streamline of poultry house without using an exhaust fan and vaporizer

Poultry house with vaporizer and without exhaust fan

In this analysis, the input and outflow were provided as windows, and the springer was regarded as the evaporator for the cooling water. Figures 10 and 11 display the temperature and velocity results from ANSYS CFD.

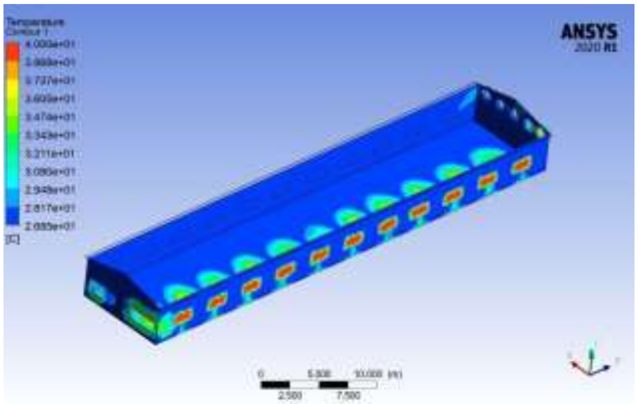

Figure 10. The temperature of poultry house with vaporizer and without exhaust fan

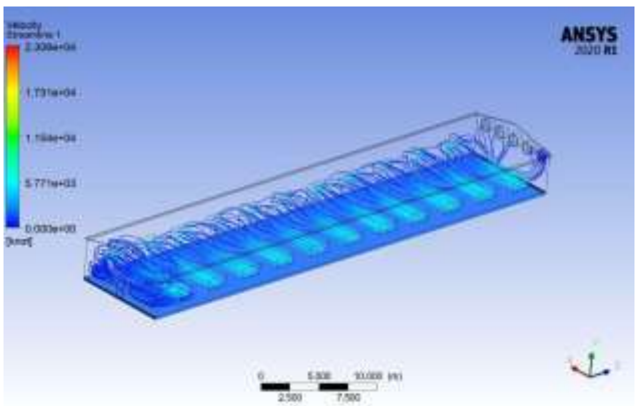

Figure 11. Velocity streamline of poultry house with vaporizer and without exhaust fan

Poultry house with exhaust fan outlet and without vaporizer

In this study, the intake was represented by windows, while a wall-mounted exhaust fan represented the output. Figures 12 and 13 show the ANSYS CFD result with temperature and velocity.

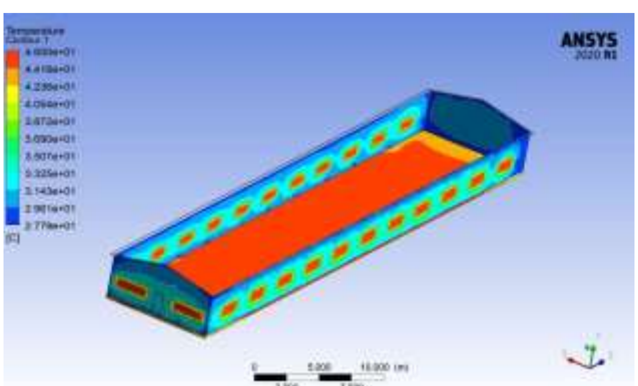

Figure 12. Temperature for poultry house with exhaust fan outlet

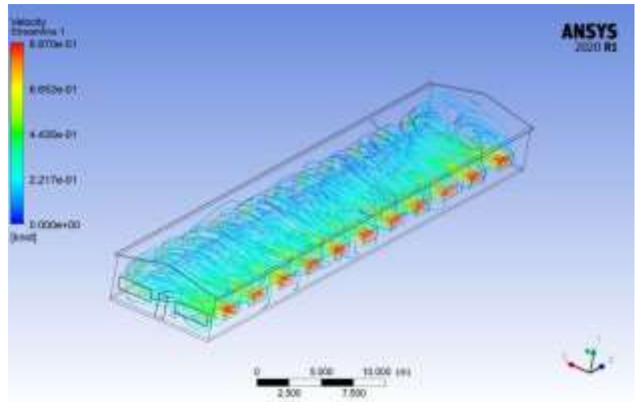

Figure 13. Velocity for poultry house with exhaust fan outlet

Poultry house with vaporizer and exhaust fan

In this part, the evaporator is employed as the cooling system, the windows are used as the input, and the exhaust fan is used as the outlet. Figures 14 and 15 show the temperature and velocity results from ANSYS CFD.

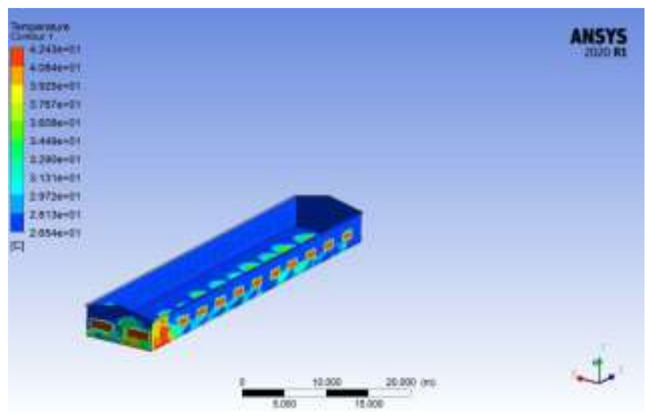

Figure 14. Temperature for poultry house with evaporator and exhaust fan

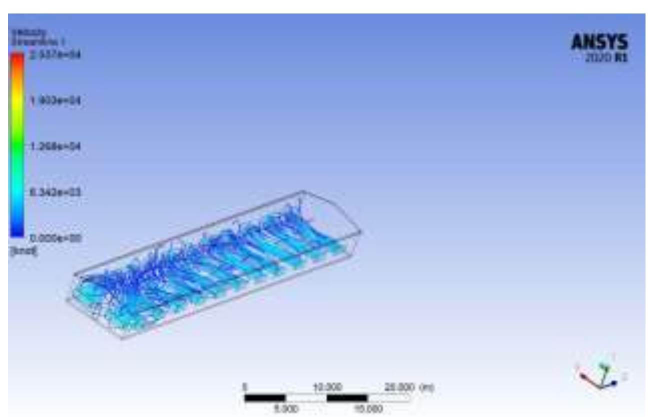

Figure 15. Velocity streamline for poultry house with evaporator and exhaust fan

Comparative analysis

The results were produced by the CFD tool under four distinct setup settings. The ambient temperature and mass flow rate for all models were 12 m/s and 40°C, respectively. Figure 8 depicts the temperature distribution on the poultry house for the first modal (poultry house without exhaust fan and vaporizer). Since it was determined from the findings that the heating is high on the floor area, the highest temperature ever recorded in the house using this model is 46°C.

The second model, a chicken coop with a vaporizer but no exhaust fan, was shown to have a maximum inside temperature of 37°C based on the temperature reduction on the floor and walls. The third model, a chicken coop without a vaporizer but with an exhaust fan outlet, showed that the outlet zone had a high temperature. The model's overall temperature is depicted in Figure 12, with the greatest temperature recorded as 36°C. The chicken house in its final form has an exhaust fan and a vaporizer as part of its ventilation and cooling systems. Figure 14 shows the results of CFD.

The x-axis in Figure 16 shows the names of models 1, 2, 3, and 4, while its y-axis displays each model's temperature. The temperature inside a chicken house was dramatically lowered by the installation of an exhaust fan and a vaporizer. Therefore, a temperature differential of 10°C may be created by the water evaporator (water springer) and exhaust fan as the air circulation system with this model. The four models' comparison graph is shown in Figure 16.

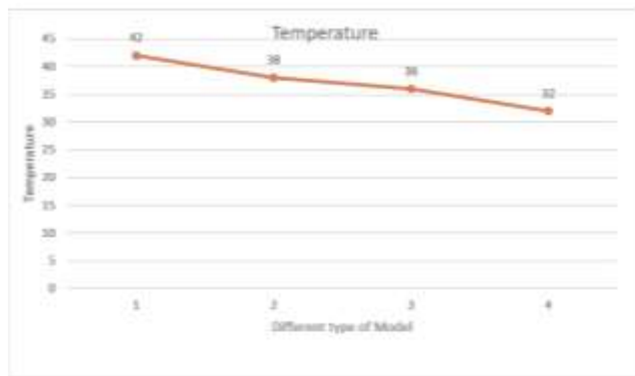

Figure 16. Result comparison chart for four analysis models.

Comparative analysis of theoretical and computation fluid dynamics analysis

This study made use of numerical analysis and computational fluid dynamics. The flow analysis was carried out using ANSYS CFD, and the numerical analysis was finished and published by Saner and Shekhawat (2022). Table 1 compares the results of theoretical and numerical analysis.

Table 1. Parameter comparison between numerical and computational fluid dynamics analysis

Input parameters	Numerical analysis	CFD analysis
Mass flow rate (kg/s)	12	12
Temperature ambient (°C)	40	40
Exhaust fan (rpm)	100	100
Ventilation window (Shutter angle in °C)	45	45
Approach	Energy balance equation (calculation)	Continuity equation and Navier strokes equation (flow analysis)

CFD: Computational fluid dynamics

Output comparisons

The internal temperature of the design was calculated numerically to be 28°C for a mass flow rate of 12 m/s and an ambient temperature of 40°C. According to the results of the CFD research, the second model suggested in the current study had an ambient temperature of 40°C and an interior temperature of 30°C with a mass flow velocity of 12 m/s. Therefore, 28°C and 30°C were the final results of both studies. As a result, the average error could be calculated as 2°C.

CONCLUSION

The ANSYS CFD was used in this project to design and assess the poultry house. Ventilation and cooling were accomplished by the evaporator and the exhaust fan. The design of the model incorporated four different analytical techniques. A poultry house without an evaporator or exhaust fan came in first, a poultry house with an evaporator but no exhaust fan was in the second phase, a poultry house with both an evaporator and an exhaust fan were in third, and a poultry house with both was presented in fourth stage. According to the CFD results, the evaporator and exhaust fan may be used to lower the temperature in the chicken house to the lowest possible level. This model could reach temperatures as high as 32°C. By applying this theory, a chicken coop could be built, keeping the birds between 30 to 32°C. Future studies on sophisticated automation and monitoring technology can enhance the inside atmosphere of chicken coops. Depending on the situation in real-time, sensors, data analytics, and machine learning algorithms may change the temperature, humidity, and ventilation. It allows dynamic adjustments to lower interior heat and provides a comfortable avian environment.

DECLARATIONS

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Authors' contributions

Kapil A. Saner wrote the original draft, methodology, study conception and design, analysis and interpretation of results, and reviewing and editing. Sanjay P. Shekhawat has conceptualized, collected data, reviewed, and edited. The authors confirmed their contribution to the paper as follows, and all authors reviewed the results and approved the final version of the manuscript.

Availability of data and materials

Not Applicable

Ethical consideration

Ethical issues, including plagiarism, consent to publish, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been checked by all authors.

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Competing interests

The corresponding author states that the authors have no competing interests on behalf of all authors.

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