Analysis of Thermally Controlled Poultry Housing Using CFD

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Authors’ contributions

This work was carried out in collaboration among all authors. Author TOT designed the study, supervised the research and wrote the first draft of the manuscript. Author FRF proofread the manuscript, managed the literature searches and edited all work. All authors carried out the experiment and provided the result. Author TOA performed the statistical analysis, wrote the protocol, worked on the design calculation and managed the analyses of the study. Author BIO supervised and provided all necessary information as regard the poultry information for simulation. All authors read and approved the final manuscript.

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ABSTRACT

Poultry industry’s development in the past two decades and the need for increased animal protein sources in the hot regions of the world, require the need to develop housing system that is thermally controlled for optimal production. The research was carried out at Federal University of Technology Akure, Ondo State, Nigeria. The facility consisted of a broiler house of 6 rooms enclosed by masonry sidewalls at the base and insulated plywood at the upper section of the house with each experimental room equipped with blower, suction fan and heater. The data were monitored at the most critical time of the day – 1 pm during the dry season. Experimental data were recorded using developed and calibrated data logger. The 5 experimental rooms are programmed to 5 temperature levels (41, 38, 35, 32 and 29°C) characterizing extreme heat boundary conditions for broilers with fans programmed at 1.5 m/s air velocity. The aim of this study is to evaluate the thermal distribution in solid-wall broiler houses using computational fluid dynamics (CFD). The CFD technique allows visualizing air flow according to different running condition for each room for exhaust fans, as well as other parameters. The simulation was used to determine the air temperature variation, inner wall temperature, external temperature, air velocity

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distribution, external wall heat flux, pressure and wall heat transfer coefficient in all the experimental rooms of poultry house. The simulated air flow pattern and temperature distribution in the experimental rooms were analyzed and the result revealed increase room temperature as the preset room temperature increases. However, the velocity profile in all the room shows buildup of air at the outlet vent due to turbulence created by the suction fans. The pressure profile across the rooms was relatively the same.

Keywords: Poultry; simulation; house; relative humidity; temperature; airflow.

1. INTRODUCTION

Nigeria poultry industry, in terms of technology and production efficiency, is still not up to the best practice standard in other developed nations, especially in the area of housing system, nutrition and heat management. Birds require specific environmental conditions of temperature, relative humidity, pressure, light, sound level, oxygen content, carbon dioxide, and nitrogen for their development. The challenge of poultry production in a tropical like Nigeria, arises because of instability in temperatures level with a very high negative effect on broiler production, especially at the brooding stage and final rearing stage. Based on these facts, the thermal environment condition (temperature, relative humidity, wind speed and solar radiation) is very important to poultry production, because it can affect broiler homeothermy responsible for guaranteeing the welfare and productive responses [1]. Broilers under heat stress present significant decreases in food consumption and growth index [2], as well as feed efficiency [3] thereby affecting their growth as a result of low feed conversion ratio. Studies found that poultry exposed to heat stress conditions have a high risk of production loss, and at critical cases can lead to animal death [4]. Thus, in the context of modern poultry production, research has shown that an inadequate environment is a vital factors influencing development of respiratory disease in birds leading to death [5]. All variables relating to the air quality inside poultry houses are determining factors in the animal husbandry environment.

In short, both ventilation system with its components (exhaust fans, PV panel, sensors, controller and operator inference) as the broiler houses (type, construction materials, insulation materials – roofs and side curtains) become important factors to determine the environmental quality, influencing the success of poultry production [6,7]. And these factors are best analysed using modelling and simulation approach. Simulation and computational methods provide a good alternative for modeling and evaluating the present problem and can be used to explore the physical relationships existing at the macroscopic level, in order to represent satisfactorily the dynamics of flows and their effects before structure is erected for the broiler house construction [8,9,10]. The deleterious effect of high temperatures can be mitigated using thermal control system systems with negative pressure and adiabatic evaporative air-cooling. This system aims to regulate the temperature inside each experimental room [11].

Reynolds-averaged Navier-Stokes (RANS) methods aim for statistical description of the flow. Time averaging is employed in Reynolds-averaged modeling to reduce the range of scales present in turbulent flows. The averaging time is much larger than the largest timescale of the turbulent fluctuations, and as a result, one ends up with conservation equations that describe the evolution of the mean flow quantities only. Flow quantities such as velocity and pressure are split into an average and fluctuation components, based on the Reynolds decomposition. The influence of the removed turbulence fluctuations on the mean flow is incorporated into the Reynolds stress tensor.

The research result in this case aimed at analyzing the fluid-dynamic behavior in a controlled poultry house Computational Fluid Dynamics (CFD) based on Reynolds-Averaged Navier-Stokes (RANS) equations in order to generate recommendations that stipulates the best thermal control system for controlled poultry house.

2. MATERIALS AND METHODS

2.1 Description of the Poultry House

The proposed controlled poultry house consists of seven rooms. Six of the seven rooms are experimental rooms and the last room is the observation and digital control room [11]. Each of the six experimental rooms spacing is 3 m by 1.5 m. Five of the six experimental rooms are thermally controlled while the last is the controlled experiment room. The five thermally
controlled rooms consist of a blower with heating element attached for hot air distribution into the room and likewise a suction fan is positioned at the top of each room to aid the easy passage of air out of the room, serving as the only source of ventilation.

The experimental rooms except the control experiment room is completely seal up with no allowance for heat loss in order not to expend more energy in attaining the desired temperature and humidity level. The fans and heater with lightening is powered by the solar system which has 4 batteries of 200 Ah, 24 volt each positioned inside the observatory room and 8 panels of 150 watt each placed on the roof of the housing directed to the southern azimuth for trapping maximum solar insolation. The solar panels are linked to a charge controller to ensure overcharging does not occur. A data logger was designed to collate environmental data from each of the rooms and was placed inside the observatory room to disallow interference of human inside the experimental room every hour. The room was sealed using ply wood with fibre glass insulation and likewise the room was sealed using asbestos with fibre glass insulation. The structural elements specification of the planned broiler housing is shown in Fig. 1.

2.2 Numeric Modeling

Air flow rates and heat transfer interactions which are two important factors in CFD simulation are usually associated with turbulent flows whose combination generate a system of equations that is difficult to solve, by nonnumeric methods. Thus, the CFD technique was used in this study based on the solution of the Reynolds number average system extracted from the Navier–Stokes equations, by discretizing the flow field and based on the finite volumes technique.

The model that describes the non-isothermal fluid flow is described by the equations of continuity, momentum and energy, simplified in the following forms [12] which are defined using equation 1 to 3.

\[ \nabla \cdot (\rho U) = 0 \]  
\[ \nabla \cdot (\rho U) = \nabla p + \left[ \mu (\nabla U + \nabla U^T) \right] \]  
\[ \nabla \cdot (-k \nabla T + \rho C_p T U) = \dot{Q} \]

The turbulent flow was modeled using the k-ε standard model, which evaluates the viscosity (\( \mu_t \)) from the relationship between the turbulent kinetic energy (k) and dissipation of turbulent kinetic energy (ε) [13] with the expression shown in equation 4.

\[ \mu_t = C_\mu \rho \frac{k^2}{\varepsilon} \]  (4)

Where the values of k-ε are obtained by equations 5 and 6:

\[ -V \cdot \left[ \left( \eta + \rho \frac{C_k \mu \kappa^2}{\sigma_k s} \right) \nabla \right] U + \rho U \cdot \nabla \kappa + \rho C_{\kappa} \frac{k^2}{s} \]  
\[ -V \cdot \left[ \left( \eta + \rho \frac{C_k \mu \kappa^2}{\sigma_k s} \right) \nabla \right] U + \rho U \cdot \nabla \varepsilon = \rho C_{\varepsilon} C_{\mu} \mu + \left( \nabla U + \nabla U^T \right)^2 - \rho C_{\varepsilon} \frac{s^2 \kappa}{\varepsilon} \]

Where,

\( \eta \) is the dynamic viscosity, \( \rho \) is the density, \( u \) is the velocity field, \( p \) is the pressure, \( Q \) is a volume force field such as gravity, \( \mu_t \) represents eddy viscosity, \( k \) is turbulent kinetic energy.

| Structural element | Structural materials used | Area of structural element (m²) |
|--------------------|---------------------------|-------------------------------|
| Floor              | Hard core and concrete skin | 5.19 m²                      |
| Walls              | Cement mortar             | 8.99 + 7.8 + 3.8 = 20.59 m²   |
| Door               | Aluminum frame glass      | 2.464 m²                     |
| Window             | Aluminum frame glass      | 1.483 m²                     |
| Roof               | Asbestos, Fibre Glass     | 5.19 cm²                     |

Table 2. Physical properties of some materials used for W (thermal conductivity W/m² °C)

| Materials      | Coefficient \( c_m \) (W/m² °C) | Thickness \( d_m \) (m) |
|----------------|---------------------------------|------------------------|
| Wooden cover   | 0.2                             | 0.02                   |
| Asbestos       | 0.465                           | 0.004                  |
| Fibre glass    | 0.04                            | 0.05                   |
| Concrete       | 1.7                             | 0.5                    |
Fig. 1. Front view of the thermally environmental control solar heated animal housing
(Note: 1 = Control experiment room; 2-6 = Thermally controlled experimental room, 7 = Observatory room)

Fig. 2. Back view of the thermally environmental control solar heated animal housing
(Note: a = blower; b = insulated plywood; c = cement brick plastered with cement mortar; d = net)

3. RESULTS AND DISCUSSION

3.1 Geometry

The initial stage of simulations in CFDs is the definition of the domain, i.e. the geometry in which to apply the numerical solution of the equations which describes the phenomena to be investigated. Domain geometry for this study was generated using Autodesk Inventor software and the simulations were performed with the ANSYS CFD FLUENT version 17.2 software. The simulation domain for the controlled poultry house consist of the rooms at different temperature without bird and no interference of observers. Each rooms were modelled based on preset temperature value ranging from 29°C, 32°C, 35°C, 38°C, 41°C. The modeled mesh density was increased at the lower part of the rooms where the main experimental reading is supposed to take place. The total number of elements and nodes varied among the different simulations and was in the range of 182,984 elements and 36,258 nodes. The mesh in regions near the walls was refined using the inflated boundary conditions tool of CFX 17.2 (Figs. 3 and 4).

3.2 Boundary Conditions for the Thermally Controlled Poultry House

The ANSYS CFX software was used in the simulations and the assumptions were as follows: steady state; single-phase flow (fluid: air); thermal energy condition; incompressible and turbulent flow. The local coefficient \( h \) did not have significant changes in any of the ducts; thus, the overall heat transfer coefficient was considered to be constant of \( 10^{-4} \) as the convergence criterion. Additionally, the dimensions and operating conditions of the air distribution duct model were used to generate
the CFD model required. Hence, the measured values of air temperature, speed and other parameters obtained in the experimental rooms for boundary conditions were averaged out and implemented in the computational model.

3.3 Simulation of Poultry Housing

The airflow, temperature, relative humidity and other parameters inside the controlled poultry house were simulated using the ANSYS-CFX 17.2 software package. The employed computational domain includes the poultry house without the broiler. The simulation was used to determine the air temperature variation, inner wall temperature, external temperature and air velocity distribution, and wall heat transfer coefficient in all the experimental rooms of poultry house. Figs. 5-9 shows the simulation model of the poultry housing for different parameters.

Fig. 5 shows the temperature distribution in the experimental rooms at different temperature levels (41, 38, 35, 32 and 29°C). The temperature profile in the building reduces along the left side of the simulation picture (41°C to 29°C) as seen in Fig. 5 except the control experiment room whose temperature profile is determined by the atmospheric condition of the experimental location. Thermal control and regulation in the poultry rooms can be achieved with the use of DC heater and blower. A moderate and negligible temperature build-up along the suction fan points were noticed in the simulation due to little space available the minimal turbulence generated by the suction fan. The simulation shows that the recorded temperature from simulation analysis did not exceed the pre-set range.

Fig. 6 shows the inner wall temperature in order to estimate the possibility of heat transfer from the experimental room outside which may cause heat loss and more energy requirement in attaining the pre-set temperature range for each room. The inner wall temperature for the structure remains at desirable level not exceeding 28°C. It is evident that the roof of the structure has a temperature range of 30 to 34°C due to direct insolation from the sun on the solar panel which in turn transfer heat to the aluminum roof sheet. The insolation from the roof sheet was controlled with the aid of asbestos with a lagging material which ensure minimum transfer of solar radiation from the roof to the room in order to ensure there is no external atmospheric interference.

Fig. 7 shows the external wall temperature simulation. To ensure that the poultry housing is fully controlled, the structure must be designed in a way that it does not allow radiation of temperature from the surrounding environment into the experimental rooms so as not to have erratic temperature level within the experimental rooms. From ANSYS CFX simulation analysis, the point at which maximum temperature radiation occur is that of the window and the dehumidifying fan locations. This rise in temperature level occur as a result of the material used for the construction of the window which is glass. At these points, the maximum temperature recorded from simulation tool was 31°C which was the maximum throughout the whole building simulation.

![Fig. 3. 3D model of the designed controlled poultry housing](image-url)
Fig. 4. Surface mesh of the designed controlled poultry housing

Fig. 5. Temperature variation inside the poultry housing (axis x, y and z directions)

Fig. 6. Inner wall temperature simulation for the poultry housing (axis x, y and z directions)
Fig. 8 shows the simulation result for air velocity distribution in all the rooms. It is evident with the simulation analysis that there was even distribution of air within the room with the aid of the blower and suction fan. The boundary condition for the air speed at which the simulation was conducted was at 0.8 m/s which according to literature is a standard air speed range for domesticated birds in a confined environment. The airspeed result based on volume for the poultry housing simulated was within the range of 0.6 to 0.8 m/s which was derived based on the analysis of ANSYS CFX, and the air velocity level within the room was maintained within this range. There is increase of air velocity only at the inlet point where the axial fan blows in hot air and also at the outlet point where the dehumidifying fan sucks out air via the dehumidifying vent. Same analysis was observed by Gençoğlan et al. [14] while simulating a controlled animal housing for turkey.

The heat wall transfer coefficient for the controlled poultry housing was represented in Fig. 9. There was even wall heat transfer coefficient all through the housing wall. The transfer coefficient was at its minimum which was at 1.360 Wm⁻²K with simulation analysis, it was deduced that the material for the poultry housing was well selected, considering also the insulation properties and lagging material to ensure there is relatively minimal heat transfer from the external environment to the internal environment of the housing.
Fig. 9. Wall heat transfer coefficient for the poultry housing (axis x, y and z directions)

4. CONCLUSION

The computational fluid dynamics technique is an efficient and reliable method for predicting airflow displacements under different operating conditions, selected material and temperature level using blower and suction fans, with the aim of determining the optimal exhaust fans speed, avoiding low air-exchange and turbulence zones. In this sense, the ventilation and thermal control system controller is capable of defining the most suitable setting for air exchange.

The proposed CFD analysis for the poultry housing was well validated with the boundary data and can be used to predict and model the dynamics of air dry bulb temperature and speed distribution inside the broiler house. This methodology could be useful as a basis for initial design of poultry houses with controlled heating and ventilation to optimize the airflow inside the building and other important parameters. The simulation was able to predict the different conditions under present range of temperature. The simulation also informed about different conditions the rooms were subjected to and the effect on different parameters as it affect broiler growth.

Furthermore, the validated CFD model can be used to test different design configurations, types of materials, and inlet air temperatures and speeds, wall heat transfer coefficient, internal and external temperature profile among other variables related to the heating systems of poultry houses that are considered the main source of the problems related to controlling the thermal environment in broiler houses.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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