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Improving broiler lifestyle: a CFD approach

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Abstract: Climate change poses environmental risks which can negatively affect livestock production. To circumvent this, it is possible to move livestock into environmentally controlled animal housings. In South Africa, this is practiced in the broiler industry. To be economically viable, it is required to build energy and cost effective housing while not compromising the health of the broilers.

A broiler's physiology is sensitive to the environment it resides in and slight fluctuations can have detrimental effects and can negatively influence the growth or health of the broiler. These houses make use of different combinations of heaters, fans and inlets to warm, cool and ventilate the house. This needs to happen within very specific parameters or it can decrease broiler performance.

We investigate how the equipment is used in current broiler houses and conclude that although this is a complex model to replicate and solve, computational fluid dynamics can assist in broiler house design.

Keywords: CFD modelling, broiler houses, environmental control, ventilation, food security

INTRODUCTION

In South Africa agriculture plays a major, if not critical, role in the formal and informal economy of the country, including food security. Climate change has the potential to lead to a decline in food production and availability, which will translate in increased food prices and hence increased vulnerability to poverty and malnutrition. The agricultural sector is dependent on climatic variables such as rainfall and temperature and changes in these variables may lead to changes in agricultural activities such as livestock production. Direct climate change impact risks on livestock production include changes in the quantity and quality of water, an increase in the prevalence of 'new animal diseases', as well as altering livestock growth rate and reproduction resulting from changes in metabolism due to temperatures exceeding the thermal comfort zone of the animals [1].

One possible mitigation mechanism is to increase the use of indoor environmentally controlled animal housing in livestock production as is the case in many Northern-hemisphere countries. Currently in South Africa this is not common practice, except in the broiler industry. One of the key requirements in managing broiler flock performance is effective environmental control inside the broiler house [2]. Figure 1 shows broilers packing together as a result of too low temperatures. Their growth rate is negatively influenced as they stop eating once packed together. Being sensitive to environmental conditions, homogeneous temperature and humidity distributions in these houses are crucial, independent of the time of year. Keeping this in mind, it is important to ventilate the houses regularly to vent the carbon dioxide, methane and dangerous pathogens while trying to keep the conditions in the house homogeneous [3,4].

Figure 1 Broilers huddling together along the sides of the broiler house due to cold spot formation

Ideally, optimum broiler comfort zone conditions will be achieved inside climate controlled broiler houses having solid side walls. However, these houses are expensive to construct, and hence the most common house design in South Africa is a curtain sided tunnel house, known as a natural ventilation house. This design poses a number of problems in terms of effective environmental control. Being able to model different ventilation modes allows us to investigate possible ways of improving the energy efficiency of these houses while still producing sufficiently large and healthy broilers.

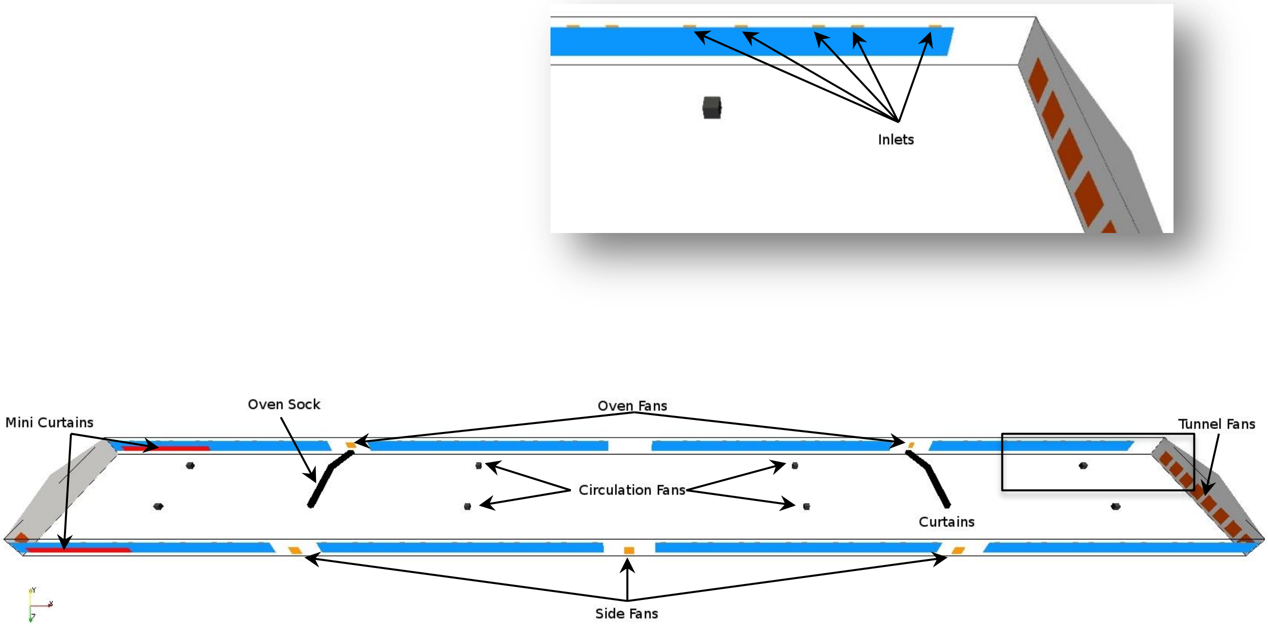

Figure 2 A bird's-eye view of the broiler house geometry used in all simulations showing all the boundary patches

Table 1 Mesh dimension and resolution used

Mesh	
Dimensions $(\boldsymbol{l} \times \boldsymbol{w} \times \boldsymbol{h})$	$\mathbf{120 \times 15 \times 38}$ meter
Resolution $(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z})$	$\mathbf{240, 60, 38}$

Quantification of indoor animal housing environmental variables has been experimentally investigated over the last few decades (see for example [3]). However, the complex nature of the phenomena involved, as well as the challenges encountered in representative up-scaling of variables from laboratory to real-life production scales, have made the use of numerical methods, such as computational fluid dynamics (CFD), to effectively quantify these variables under different simulated design conditions more attractive (see review by [5], [6,7]). In this study we aim to investigate air-flow patterns and temperature control inside a natural ventilation broiler house using CFD. The structure design will be utilised as part of an investigation into climate control optimisation inside currently existing broiler houses in order to assist the chicken production industry in formulating and implementing climate change adaptation strategies. Design requirements include (see Figure 2):

- Climate control inside the building, while operating within an outdoor temperature range of -2 to 38 °C.

- The use of natural ventilation combined with extractor fans to ventilate the building. The system should provide proficient oxygen to the birds without causing drafts at bird level and maintain optimum temperature conditions.

THEORETICAL FRAMEWORK

Currently, broiler house designs are mainly informed by experience. The dimensions of the house and the amount of broilers the house is required to hold, will determine how much air needs to be evacuated and replenished on a regular basis. Considering the budget of the farmer and using the specifications supplied by the equipment's manufacturer, the designer will configure a house suited to the climate of where it will be located. CFD can assist with the design of the house to determine an optimal configuration taking into account the climate and equipment prescribed.

Before simulating broiler houses, one needs to understand the equipment used and how it influences the physics of the environmental variables present in a house. These houses need to be able to maintain the broilers' thermal comfort zone, as well as evacuate any contaminants and gases produced by the broilers and pathogens that can negatively influence broiler health. This is achieved by a combination of inlets, circulation and extractor fans and a variety of possible heaters [2]. A house containing 20 000 – 40 000 broilers produce a significant amount of greenhouse gases and contaminants which need to be evacuated from the house continuously. This is achieved by using the fans located on the side, generating negative pressure inside the house. Small adjustable inlets located alongside the house while the side fans are operating, allows fresh air to enter the house. This configuration is known as minimum ventilation [8]. Ventilating a house during winter is challenging. Replenishing it with cold air from outside will compromise the warmer temperature required by the broilers. To introduce fresh air, side fans are activated and inlets are positioned to direct the cold air to mix with the warm air contained in the canopy of the house. Cold air will not reach the broilers, thus circumventing the winter ventilation problem.

With multiple heat sources and fluctuating ambient outside temperature, we will assume air is a buoyant, turbulent fluid. Different approaches can be used to model buoyant flow by means of the Navier-Stokes equations. The compressible fluid, having a variable density, will automatically accommodate the buoyancy assumption if gravity has been defined, while we use the Boussinesq approximation for the incompressible fluid. The Boussinesq approximation uses the temperature and a thermal expansion coefficient (β) to determine the driving density of this incompressible fluid.

Boussinesq approximation: $$\rho/\rho_{reference} = \rho_{effective} = 1.0 - \beta(T - T_{reference}) \tag{1}$$

Momentum Equation: $$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{\partial}{\partial x_i}\left(\frac{P}{\rho_{ref}} + gz\right) - \beta g\left(T_{ref} - T\right)\delta_{i3} + \nu \Delta u_i \tag{2}$$

Temperature Equation: $$\frac{\partial T}{\partial t} - \frac{\partial}{\partial x_j} u_j T - \frac{\partial}{\partial x_k}\left(K_{eff} \frac{\partial T}{\partial x_k}\right) = 0 \tag{3}$$

OpenFOAM, an open-source, multi-physics toolbox, will be used. OpenFOAM's library of solvers contains a myriad of different applications, supplying solutions to different problems. In this library we find solvers with the ability to model buoyancy flow with different types of models.

For our broiler house model, we will run steady-state simulations using Boussinesq's equations and the SIMPLE algorithm. The buoyantBoussinesqSimpleFoam standard solver in OpenFOAM v2.1.1 was used unchanged, i.e. no modifications were made, using second order discretization schemes. This assumption is sufficient given that the transient event is much faster than the steady-state conditions required inside the house, e.g. fans and heaters are point sources of ventilation that can be switched on or off, with the intention to reach steady state soon. The actual transient is not that important. The transient event can be approximated by interpolation between various steady-state calculations at various operational conditions taking into account the daily and seasonal fluctuations. It's more important exploiting the complex geometry representing the myriad of equipment as seen in Figure 2, as it will still allow us to investigate different ventilation and heating scenarios and how it will influence broiler performance.

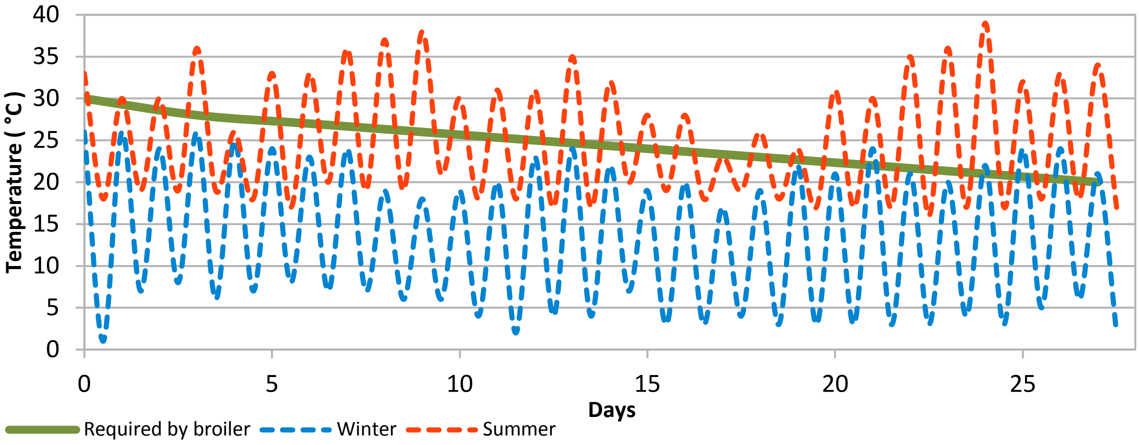

Figure 3 The temperature required by broilers during their 27 day life cycle [8] and day-night temperature fluctuations experienced during a typical winter and summer month

RESULTS AND DISCUSSION

Due to changes in their ability to regulate their body temperature, the broilers' thermal comfort zone changes during different stages of their development, as shown in Figure 3. This implies that the broilers need to be heated in cold nights and during cold winter days and cooled down during hot summer days. Considering the daily temperature fluctuations experienced by the broiler house, it becomes apparent that sufficient control over the equipment is required to maintain the broilers' body temperature. By modelling different active configurations of the equipment, we can investigate how it influences the environment inside a house.

To warm the broilers, various heating equipment are available [2]. In our sample case, we will use ovens fuelled by coal. Unlike heating lamps and other devices, the two ovens are located outside the house. Air is extracted from the house by fans, it is heated by the oven and then reintroduced to the house through a plastic tube (sock) which spans almost the entire width of the house through four multi-directional outlets (Figure 4). Warm air is further distributed throughout the house using eight strategically placed circulation fans. Warm air will be distributed close to the ceiling of the house, gradually warming the house from top to bottom. It should be noted that the oven fans operate continuously, while the oven is only used when the temperature in the house need to be raised.

Figure 4 View inside broiler house

Table 2 Initial and Boundary Conditions used in OpenFOAM cases

	Magnitude of Velocity (m/s)	Temperature (K)	Pressure (m^2/s^2)
Walls/ Inlets Boundaries	0	300	calculated
Circulation Fans	cyclic / 0	cyclic	calculated
Oven	0	320	100000
Internal Initial Conditions	0	300	99960
Convergence	1e-5	1e-5	1e-5
Relaxation Factors	0.3	0.5	0.7

Table 3 Simulation parameters

	Case 0	Case 1
Initial Conditions		
- Temperature (K)	300	
- Velocity (m/s)	Initialized by a potential flow solver	
Oven	Active	Active
- Velocity	4.15	
- Temperature	320	
Circulation Fans	Inactive	Active
- Velocity	0	6.2

As a benchmark, consider a closed house with only the ovens operating (see Case 0 in Table 3). We will attempt to raise the ambient temperature in the house by only a few kelvin. The oven will force hot air into the house through outlets in the socks as seen in Figure 4.

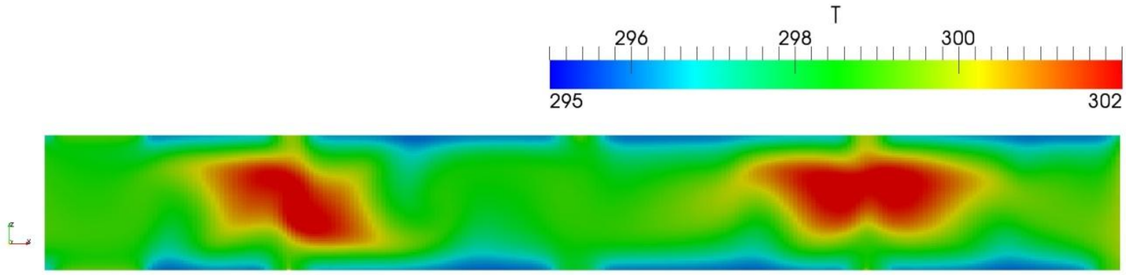

Figure 5 Temperature profile at broiler level when only the ovens are active

Figure 6 Vertical cross-sectional temperature profile through the length of the house

The simulated results are shown in Figures 5 and 6. At first glance it is clear that although the solution has converged, the results are not satisfactory due to the fact that the oven outlets behave as point sources. The temperature distribution is uneven, creating hot and cold spots along the sides of the house at the level where it influences the broilers. High temperature gradients are visible at certain areas as shown in the vertical cross-section through the centre of the house (Figure 6).

With the addition of eight circulation fans throughout the house, a clear improvement in the temperature distribution can be seen (Figures 7 and 8). The temperature distribution is more homogeneous at bird level (Figure 7). Colder areas can be seen along the sides of the house, consistent with operational observations in a similar broiler house as shown in Figure 1.

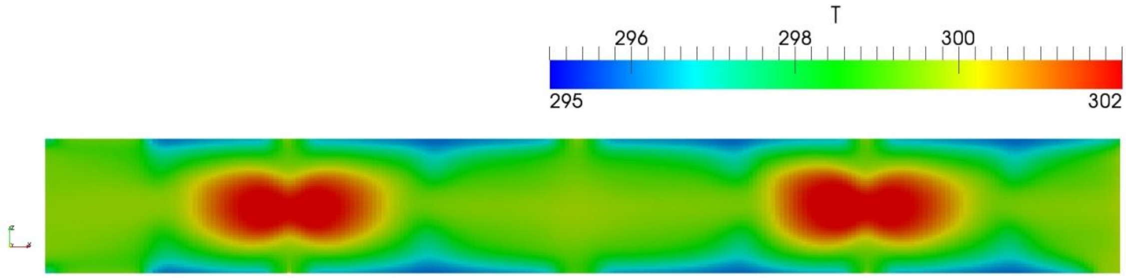

Figure 7 Temperature profile at broiler level when the ovens and circulation fans are active

Figure 8 Vertical cross-sectional temperature profile through the length of the house when the ovens and circulation fans are active

Ventilation of the house needs to occur without producing air velocities higher than 1 m/s at the level of the broilers [8]. Higher velocities can negatively affect the health and growth rate of a broiler [8]. The younger the broiler, the less of a draft it can tolerate. Only after it has its full adult plumage, can it tolerate moderate air velocities higher than 1 m/s.

Table 4 Maximum air velocity experienced by broilers to avoid the wind-chill effect [8]

Age (days)	Maximum air velocity (m/s)
0-14	0.3
15-21	0.5
22-28	0.875
28+	1.75-3.0

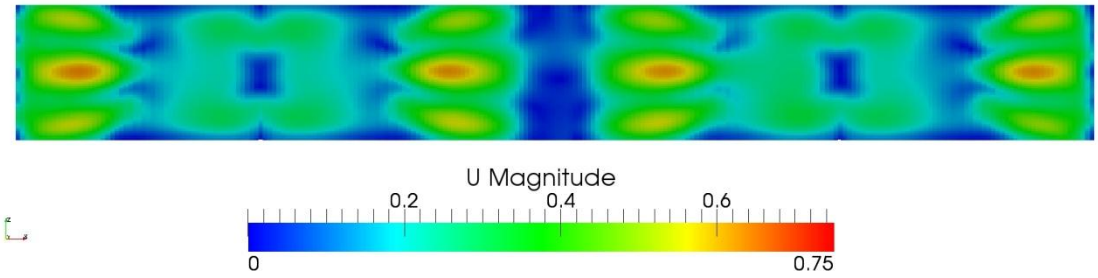

Figure 9 Velocity profile at bird level for conditions as presented in Figures 7 and 8

Figure 9 indicates the velocity profile at bird level has a fairly even distribution, having velocities below the recommended level (refer to Table 4). This confirms that the CFD model is able to replicate environmental conditions in an operational broiler house.

CONCLUSION

The CFD modelling of the combined interior-exterior environment remains a challenge. Steady-state solutions for the interior conditions of a broiler house have been presented, taking into account the heating and ventilation equipment and complex boundaries. The results confirmed operational observations of hot and cold spots. The next step will be to model the transient effects using interpolation between different steady-states. This is work in progress towards the using of optimisation techniques to create homogeneous conditions to improve broiler lifestyle.

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