A numerical CFD method for the broiler house ventilation analysis

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Abstract

The need of an exact control of the temperature, humidity and air velocity is main reason, why the application of different simulation methods is very suitable and progressive help for designers and researchers. This paper is focused on the numerical analysis of ventilation of building for broilers during the summer and winter periods with the use of computer fluid dynamics (CFD) software Fluent. There are specific problems inside the buildings for broilers, because they are growing in artificial conditions since the first day of their lives (several grams of the weight) to the end of fattening (several kilograms). Especially summer period with highest outside temperatures at the end of fattening period and winter period for one day chickens with low outside temperatures are problematic.

Keywords: poultry, air, velocity, temperature, CFD

Introduction

The aim of this paper is a numerical analysis of the ventilation of buildings for broilers during the winter and summer period. Air flow rate in the animal's residence zone is one of the main parameters affecting the formation of suitable internal environment, which is required for broilers. A specific problem of such halls is the fact that chickens are kept permanently inside the facility from the first day of their life (a few grams in weight) until the end of the fattening process (up to the weight of several kilograms). The biological production and the thermoregulatory abilities of chicken are significantly changeable during the fattening period. Problems with creating an internal environment becomes mostly important in the summer at the end of the fattening period and during the winter after loading of small day-old chicks. The overheating of chickens has a bad influence for broiler performance (Lott, 1998) and also the overall quality of air is very important (Xin, 2001 and Bessei, 2006). The basic problems of ventilation of broiler house are solved by using mathematical simulation is to determine the flow rate and velocity field in a ventilated area.

The Fluent CFD software is used as a universal tool for numerical analysis of fluid flow and thermal analysis. Influence of the geometrical shape and velocity field on thermal field was also monitored.

Effective distribution of fresh air inside the building, and the corresponding locations of inlets and exhaust outlets contribute to the effectiveness of ventilation components. The thermal analysis were also dealt with extreme temperature conditions inside the interior during a partial and complete failure of the ventilation system and leads to evaluation of the effect and consequences of indoor microclimatic conditions.

Numerical flow simulations (CFD - Computer Fluid Dynamics) are successfully used to solve technical problems in various industry branches for many years. Air conditioning and ventilation has undoubtedly wide range of applications relevant to the investigation using CFD and can be successfully used for agricultural applications (Gascone, 2006).

The reason for the use of numerical analysis is driven in most cases by need of detailed understanding the flow shape in a ventilated area and often with the possibility of simulation of conditions, which are practically unobtainable and unacceptable form operational reasons, except of an emergency situations. This work is the next step in the analyzing of applicability of FLUENT for such kind of problems (Kic, 2009).

The numerical analysis of specific ventilated area with an emphasis on achieving the best possible agreement with the numerical model of the measurement is performed. The commercial computer system Fluent is used for a solution, along with the pre-processor Gambit.

Methods

If the numerical model is used to predict the state of the system for different than the measured conditions it is necessary - for its correct function - to tune it on a state consistent with the experiment. For this reason it is necessary to use experimental data and made the validation. It is good to get several sets of measurements for different operating conditions.

University farm

Content of this article is based on the measurements, which took place in the broiler house in University farm and there were made under normal operation conditions. Basic geometric dimensions of the hall are: length 41 m, width of 17.2 m and height at it's highest point is 4 m. The actual layout of the hall can be seen from the photos on the figure 1.

Figure 1. A real, external and internal layout of buildings in University farm. Important are vents in the ceiling of poultry, which are fitted with sliding plates, which are used by operating staff to regulate the intensity (amount) of exhaust air from the broiler house.

Totally 15 400 one week old chickens was present inside the hall during the measurement. The weight of a chicken at the time of loading was about 37 g and at the time of measurement it ranged between 123 and 128 g. The ventilation system was set up as for a summer conditions, since the outside temperature was 21 °C. The hall itself was build as the reconstruction and modernization of older buildings; hence it has an atypical and asymmetrical shape. Most common farm buildings have the inner area characterized by a simple rectangular profile.

The velocity profile, temperature profile and concentration profile of carbon dioxide at a height of 0.2 m above the floor was measured inside the hall and in the transverse axis of the hall. The measuring device used for experiment was ALMEMO 2590-9 bearing with probes for velocity and temperature sensors (thermoanemometer FV A645) sensor for measuring humidity (FHA6x6) and sensor for measuring CO_2 concentration (FVA600). Results are summarized in the graph in figure 2.

Relatively inhomogeneous conditions were adjusted due to the operating system practice used by operating staff, thrust fan was set to maximum intensity and the intensity of air flow was regulated only by sliding ceiling panels. Three fans of total amount of ten were out of order and the intake of outside air through windows was set in various intensities. It was noted, during closer inspection, that the direction of intake air stream is parallel to the floor due to its shaping inside the window channel. Outside intake roofs can be seen at the photograph.

The measurement was made at the space without broken fans, because it can be assumed that their remoteness will affect the measuring insignificantly and will have neglectable influence onto the shape of measured profiles. Fan airflow during the measurement was not choking and inlets inside the windows had a constant size. Recommended amount of exhausted air was obtained by calculation according to CSN 73 0543-2 [3].

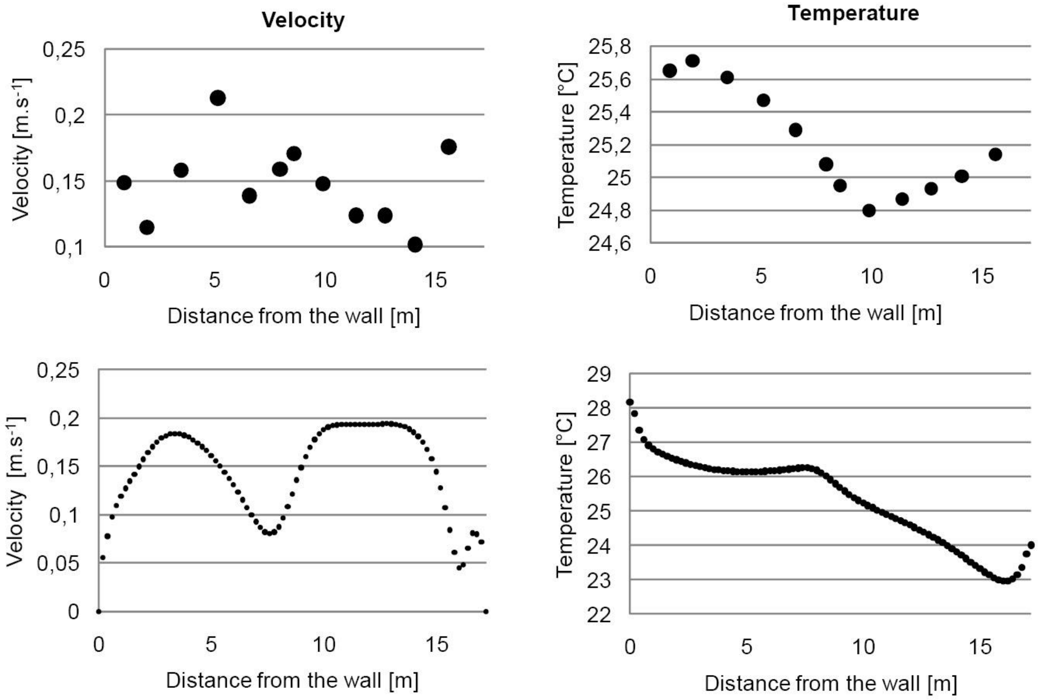

Figure 2. Comparison of two measurements, speed and temperature profiles obtained by numerical calculations for 2D geometry. Measurement and evaluation of the profile corresponds to the axis of the output ventilation channel (fan) at a height of 0.2 m above the ground.

Numerical Solution

CFD analysis is done on a meshed geometrical model. Geometrical model of the hall is a considerable idealization of the real situation, since the real 3D flow in the hall is in real conditions, as opposed to geometry and mathematical model used for the numerical analysis. The real state is overloaded with many facts which should be known during the simulation, but can be hardly added into the model.

Especially there have to be mentioned the uneven shapes of input and output fields arising due to their varying aperture and leakage. They often cause drainage or intake of an air in different areas than are defined in model. It is also difficult to define local and moving heat sources, which should represent individual chickens, and therefore the model is simplified in this direction - so the heat is inside the space supplied evenly, through all surface of the floor. Results presented here also exclude the impact of natural convection and no built-in apparatuses aren't included inside the model. Discrepancies between measured and calculated values are largely caused due those simplifications.

Two-dimensional model

It was seen, that after initial experiments with the 3D model of the hall the number of variables and sensitivity to the shape of solution is so high and threfore there is no other choice than to make a simplified 2D analysis, and tune the 3D on it's bases. Simplification of the 2D model is mainly reached by fact that the calculation domain is chosen as a cross section of the hall, including both the window and the fan, which can be imagined as only a projection of the 3D reality into a characteristic shape, which makes it possible to calculate the basic balances and get an idea about fluxes, velocities and so on, but not a detailed description of flow in 3D space. Heat generated by the poultry is delivered evenly to the model as a layer of thickness of 15 cm above the floor. Boundary conditions in this case (in Fluent terminology) "pressure outlet" input and "exhaust fan" in the output. Condition "pressure outlet" is really used as an input. In practice this means that the flow in the boundary condition area will be developed as a consequence of the pressure difference between the window and the fan creating an underpressure.

Tuning 2D model

The flow field was at first calculated with demand that the measured value of the average velocity in the plane of measurement corresponded to the numerical solution. The heat conduction equation and boundary conditions accompanied by both the temperature at the inlet and the volumetric heat source, representing the heat developed by poultry was added into the numerical model subsequently. The intensity of volumetric heat source was re-tuned as to achieve the best possible agreement with the measured values.
Figure 3 shows the shape of the temperature field corresponding to the temperature profile from Figure 2

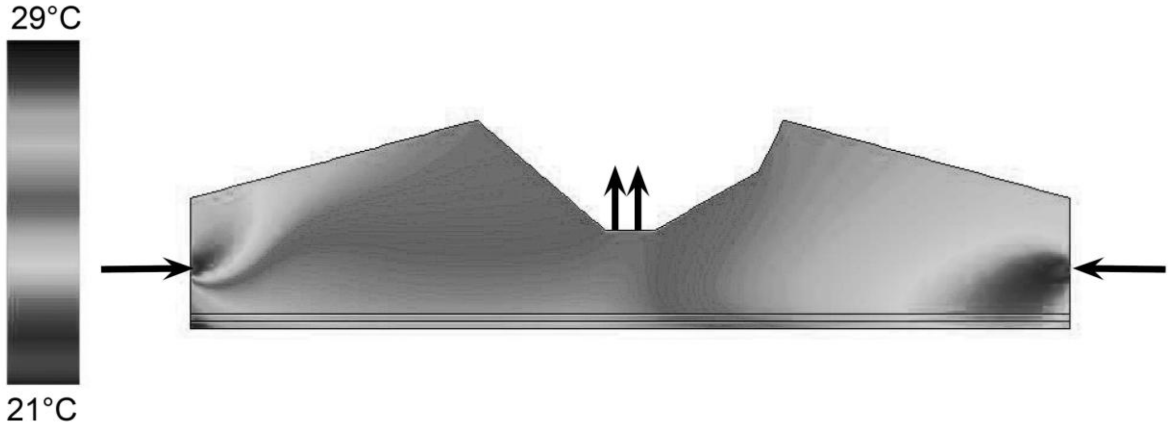

Figure 3. Shape of the temperature field in normal working order obtained from the 2D model. Inputs and outputs are indicated by arrows.

Solution of the transition state - the temperature rise in the failure of the ventilation system

Fluent allows solving of the time evolution problem arising from one steady state of the system towards another. The already well-known shape should be used as an initial condition and flow and temperature profile can be obtained from the prediction of system behaviour when changing the boundary conditions. The case solved here arises by turning the fan off. Figure. 4 illustrates the course of temperature increasing during the 0-20 minutes time period after turning off the ventilator.
The time dependant analysis is a relatively very time consuming for computing power, because it is needed to calculate the converged solution at each time step (typically about 10 to 20 iterations). While the 2D task is a matter of seconds for the 3D task it can be the order of tens to hundreds of seconds depending on the speed of the computer and model size. The 2D model is withal useful enough to estimate the critical time needed to restore ventilation, because in case of power loss there are not certainly important the local excess of critical temperatures, but the most important is the time when the overall indoor temperature exceeds the value at which the death of poultry come on.
It is possible to solve time dependent cases for two-dimensional model also for different situations, for example if it is needed the shape change of the temperature field after starting fans, or after the rise of emergency ventilation system.

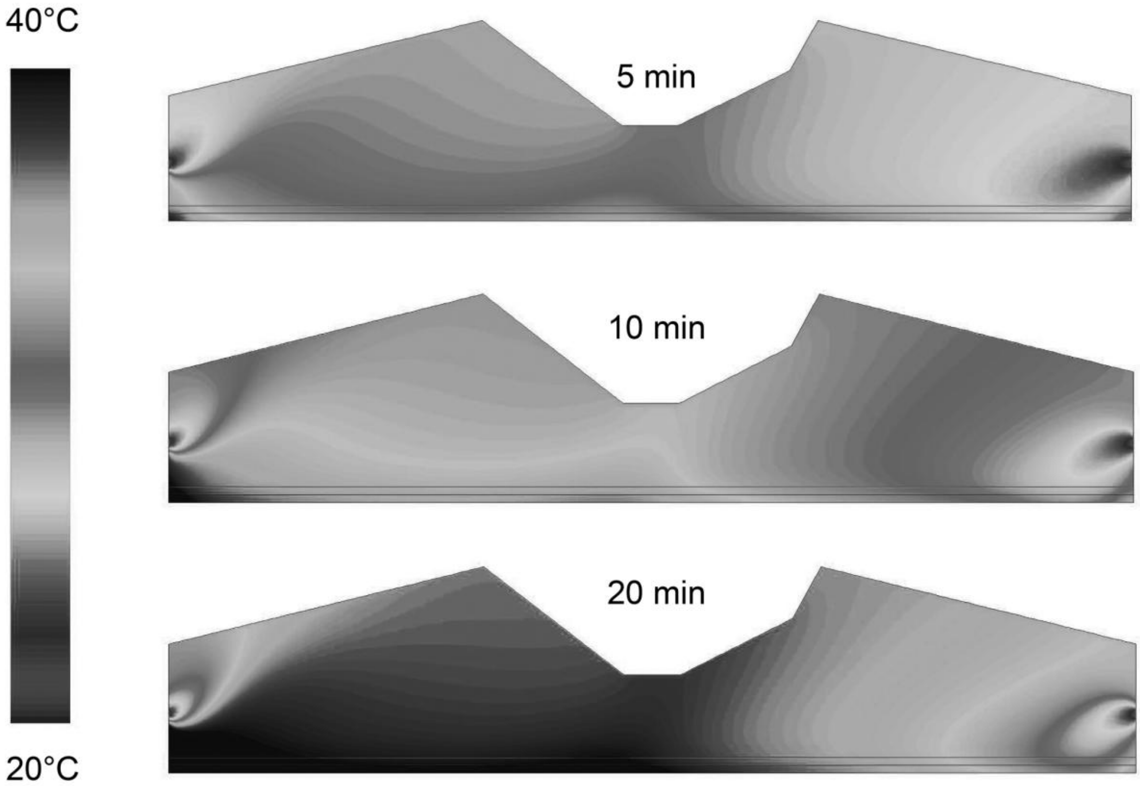

Figure 4. Illustration of the temperature rise after the ventilator is switched off. Slow melting of temperature gradient is caused by the negligence of natural convection. However, such information is sufficient enough for an idea of the overall temperature rising.

Three-dimensional model

Creating 3D models is a time consuming activity which increases the number of computational cells, prolongs the time of calculation, and increases the demands on the hardware. But the 3D model is absolutely necessary if various conditions of flow and temperature conditions in the building have to be obtained precisely. Such 3D model can bring information about the physical characteristics under normal, but also under extreme (practically unapproachable) conditions.

The values of boundary conditions derived from the 2D model are a first approximation of the boundary conditions values for 3D calculations. As already mentioned, the geometry of the 3D model provides the calculation with real spatial layout of the building and it also includes the axial components of velocities. Thus a refined model provides more detailed and realistic view of conditions inside the hall, and allows multiple ways to influence the shape of the solution. Spatial model also allows much detailed view onto critical points of the computational domain (extreme speed, temperature, swirl etc.).

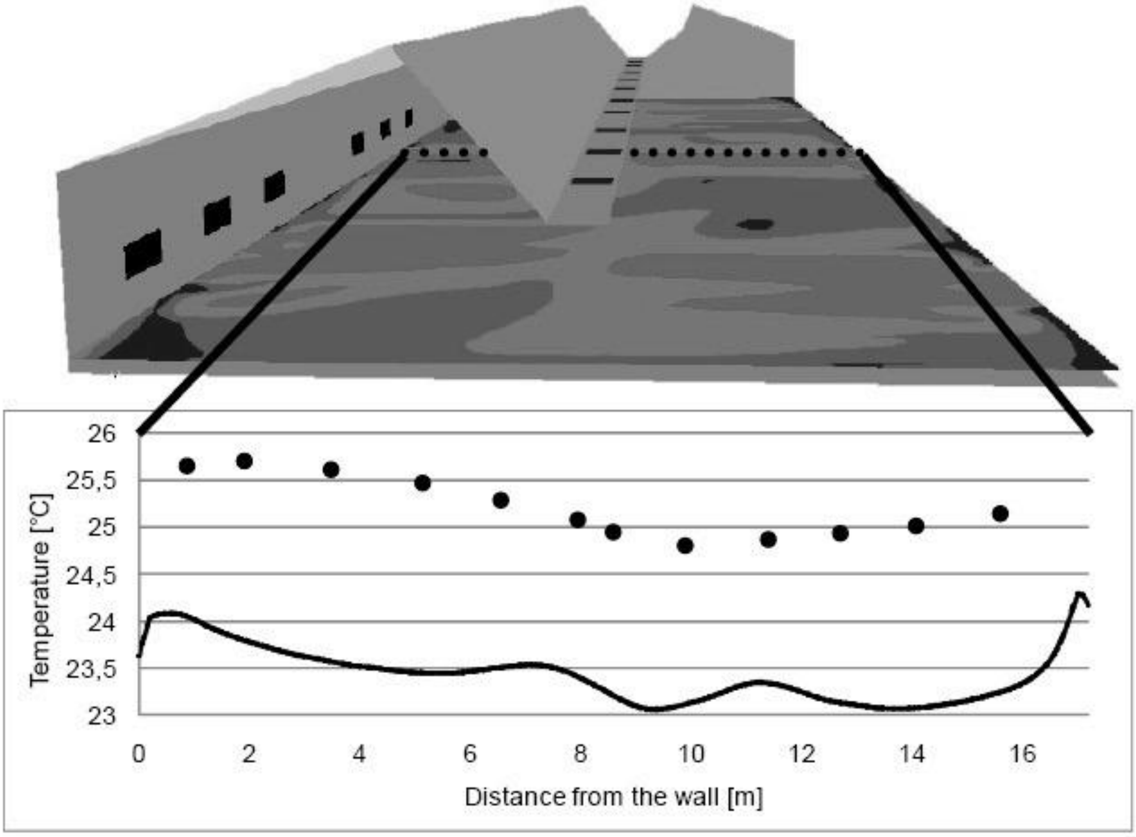

Figure 5. Comparison of measured values and temperature profiles obtained by numerical calculations in 3D. Measurement and evaluation of the profile corresponds to the axis of the output channel ventilation (fan) at a height of 0.2 m above the ground. Surface contour corresponds to the temperature distribution in the plane of measurement.

One of the possible results of the 3D analysis of broiler house is shown in Figure 5. The comparison of the measured values of the temperature profile with the profile obtained by numerical simulations can be seen there. The two degree shift between measurement and calculation can be seen quite clearly. It is certainly possible to "wipe" further tweaking the 3D model. Due to the similar course of measured and calculated values it can be noted that the model in this case is well-tuned and is suitable for further analysis.

Results and discussion

Data from measurements of velocity profile show relatively large dispersion, and their similarity with the numerical results of 2D model is only approximate. It can be mentioned that such differences are involved by geometrical simplification of CFD model and also by the fact that the 2D model does not include the axial velocity component in the longitudinal direction of the hall, which obviously affected the measuring. Character of the temperature profile is important from the CFD point of view because the numerical solution shows that models for both dimensions give the results corresponding with measurement. Therefore, it can be noted, that the fit of presented models with the measurement is satisfactory.

For more accurate and better results the potential effect of simplifying of the CFD model according to the reality has to be considered. Differences between the modelled and actual velocity field is mainly due to leaks and slits in the walls of poultry, which are not included into the model. The direction of air entering the internal space is not mathematically perfect. Since the opening of windows is not exactly the same at all inlets, the model has the same boundary condition at every of them. Therefore it has to be considered that the resulting flow field is the idealization of the real situation. Another aspect which should take the influence on the shape of the temperature field is the fact that the presented model does not include the heat transfer through walls. All the heat, which is generated inside the modelled broiler house, is transferred out of domain only due the airflow, and it entirely does not correspond exactly to the reality, as well as the fact that during summer the partial income of heat can be expected from the roof warmed by sun. The fact that the model assumes a uniform distribution of the poultry floor area is also considered, but it is again quite unreal fact, because the reality could be only described as thousands of moving thermal sources corresponding to individual chickens, but such kind of boundary condition is practically unimaginable to be included into model.

Conclusion

The 2D and 3D numerical model of the broiler house based on experimental measurements show the applicability and justification to use CFD for solving practical problems in the area of agricultural buildings ventilation. Finally it has to be highlighted, that the ventilation of the broiler house (just as other similar structures) is a complex process in which always varying a lot of factors at the same time, for example technical, biological, human and also random factors.

The construction of ventilation equipment has responded to the issues of its day with innovation after innovation for a long time. Today's challenges are centred around saving energy, minimizing operating costs, and improving comfort. To stay ahead of the competition, the most innovative designers use virtual simulation to understand the impact of their design decisions, ranging from global conditions to architectural details to materials to heating and cooling. CFD engineering simulation software offers designers, engineers and construction companies the most automated, efficient and cost-effective simulation methods available. Optimizing a design before any construction begins is the best way to avoid time and cost overruns. Ensuring that individual structural components work properly, designing HVAC equipment, modelling airflow for increasing the thermal comfort, and analyzing environmental conditions are all possible through CFD engineering simulation software and as it seen, also for agricultural applications.

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