SIMULATION OF THE BROILER HOUSE VENTILATION

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The need to exactly check and control indoor ventilation in buildings is the reason making the designers and researchers apply different simulation methods. This paper is focused on the numerical analysis of ventilation of a broiler house during the summer period with the use of computer fluid dynamics (CFD) software Fluent. Especially the summer period is critical. This paper presents the result of measurement and CFD analysis of the flow pattern, thermal state, and concentration of CO_2 and NH_3 inside the broiler house. Calculation respected the Czech standard. Final results show the improved arrangement of the ventilation system for summer conditions.

poultry; building; tunnel ventilation

INTRODUCTION

Numerical analysis of ventilation of a broiler house during the summer period was carried out. Air flow rate in the animals' residence zone is one of the main parameters affecting the creation of a suitable internal environment. A specific problem of such buildings is the fact that chickens are kept permanently inside the facility from the first day of their life (a few g in weight) until the end of the fattening process (up to several kg). The biological production and the thermoregulatory abilities of chickens are significantly changing during the fattening period. Creating a suitable internal environment is problematic mainly at the end of the fattening period in summer and after loading of small one-day-old chicks in winter. The proper flow rate and velocity field in the ventilated area can be determined by mathematical simulation.

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

Effective distribution of fresh air inside the building, and corresponding location of inlets and exhaust outlets contribute to the effectiveness of the ventilation components.

Numerical flow simulations (CFD – Computer Fluid Dynamics) have successfully been used to resolve technical problems in various industrial branches for many years. Air conditioning and ventilation have undoubtedly a wide range of applications relevant to the investigation using the Fluent CFD software (Cascone et al., 2006a, 2006b).

The reason for the use of numerical analysis is mostly driven by the need of a detailed understanding the flow pattern in the ventilated area and often by the possible simulation of emergency situations. This research represents the next step in analyzing the applicability of the Fluent FCD software to such a kind of problems (Kic, Zajicek, 2010). The method may be applied e.g. also in greenhouses, where the problems are similar (Wang et al., 2012).

The numerical analysis of the specific ventilated area was performed with an emphasis on achieving the best possible agreement with the numerical model of the measurement. The commercial computer system Fluent along with the pre-processor Gambit (Anonymous, 2006) were used for the analysis.

MATERIAL AND METHODS

The present article is based on the measurements, which took place in a broiler house in Northern Bohemia. The measurements were taken under normal operation conditions. Basic geometric dimensions of the hall are as follows: length 62 m, width 8 m in the front part and 6.2 m in the rear, maximum height 3.4 m. The building has 21 windows on the right side and 6 ventilators on the left side. The actual layout of the hall is given in Fig. 1.

The velocity sensor, temperature and humidity sensor, and sensors for CO_2 and NH_3 concentration measurement were mounted on a mobile construction which was manually moved through the broiler house.

Totally 7 500 three-week-old chickens were present inside the hall during the measurement. Weight of

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a chicken at the time of loading was about 37 g and at the time of measurement it was about 1 kg. The ventilation system was set up as for summer conditions, since the outside temperature was 21.7°C. The hall, being part of older reconstructed objects, was rebuilt and modernized; hence it has an atypical and asymmetrical shape. The transversal ventilation system is also placed asymmetrically and the first zone has no ventilator at all, as can be seen on the geometrical model in Fig. 1.

The velocity profile, temperature profile, and concentration profile of CO_2 and NH_3 was measured at a height of 0.3 m above the floor inside the hall, along the transversal axis of the hall. The measuring device used for the experiment was ALMEMO 2590-9 bearing with probes for velocity and temperature sensors (thermoanemometer FV A645), sensor for measuring temperature and humidity (FHA 646), sensor for measuring concentration of CO_2 (FY A600), and NH_3 (ADOS 592). All devices are products of AHLBORN Mess-und regelungstechnik GmbH, Eichenfeldstrasse 1-3, D-83607 Holzkirchen, Germany, http://www.ahlborn.de/.

Numerical solution

The CFD analysis is performed on a meshed geometrical model (Fig. 1). The geometrical model of the broiler house is a considerable idealization of the actual 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 the uneven shapes of input and output fields arising due to their varying aperture and leakage are to be mentioned. They often cause drainage or intake of air at other places than are defined in the model. It is also difficult to define local and moving heat sources (the individual chickens), and therefore the model is simplified in this direction. So the heat and also animal's production of CO_2 and NH_3 are supplied evenly, through the whole surface of the floor. Natural convection is also included in this model. Discrepancies between measured and calculated values are largely caused by those simplifications.

Species transport equations in Fluent FCD software

The Fluent FCD software predicts the local mass fraction of each species Y_i through the solution of a convection-diffusion equation for the $i^{\text{-th}}$ species. This conservation equation takes the following general form:

$$\frac{\partial}{\partial t}\left(\rho Y_i\right)+\nabla\cdot\left(\rho\vec{v}Y_i\right)=-\nabla\cdot\overrightarrow{J_i}+R_i+S_i \qquad (1)$$

where:
R_i = net rate of production of species i by chemical reaction
S_i = rate of creation by addition from the dispersed phase plus any user-defined sources
J_i = diffusion flux of species i, which arises due to gradients of concentration and temperature.

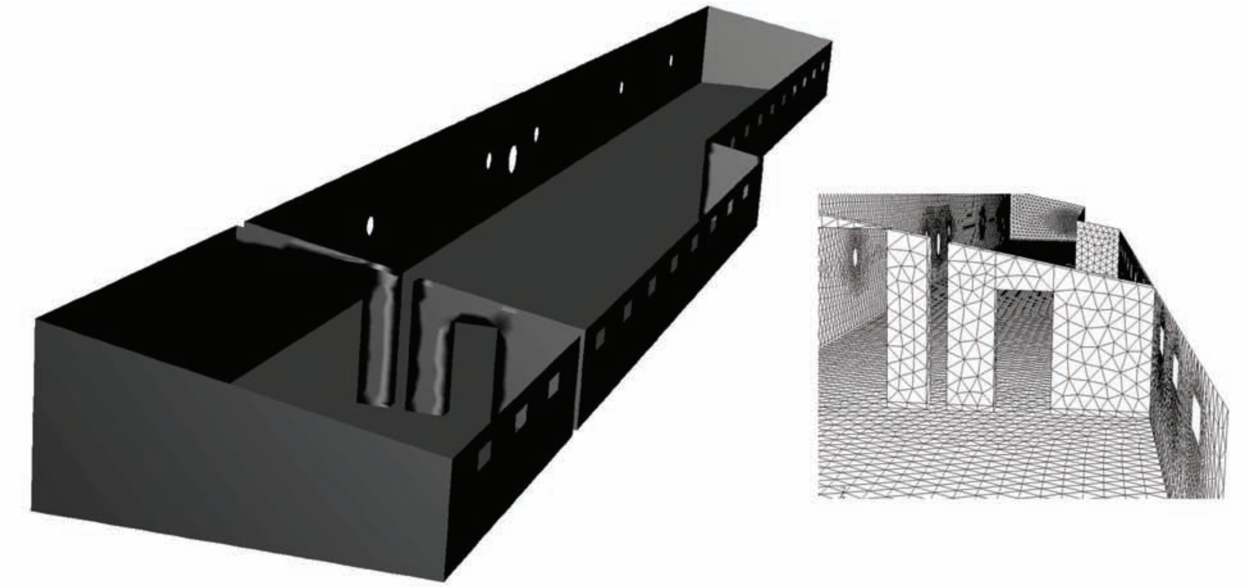

Fig. 1. Geometrical model and the detail of the surface mesh of the computational domain

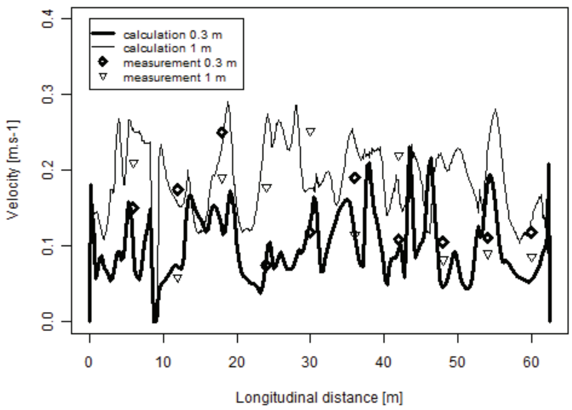

Fig. 2. The comparison of velocity profiles along the broiler house

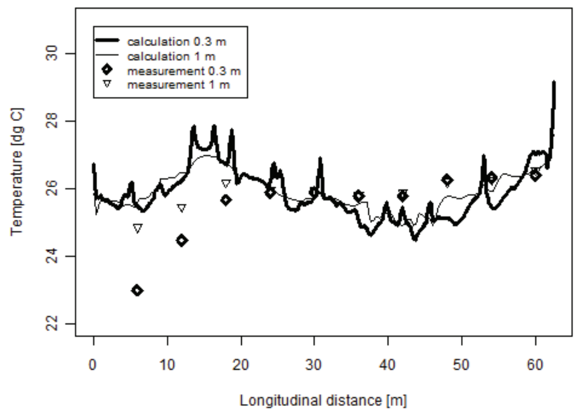

Fig. 3. The comparison of temperature profiles along the broiler house

An equation of this form will be calculated for $n - 1$ species where n is the total number of fluid phase chemical species present in the system. Since the mass fraction of the species must sum to unity, the n^{-th} mass fraction is determined as one minus the sum of the $n - 1$ solved mass fractions. Therefore the mass fraction of CO_2 and NH_3 are solved and mass fraction of air is the addition up to one.

Boundary conditions

The external temperature and concentration of CO_2 and NH_3 were given as boundary conditions at the inlet. The volumetric heat source and production of CO_2 and NH_3 were considered in the zone of chickens' occurrence. The numerical values were obtained according to the standard (C S N 73 0543-2, 1998).

RESULTS

The comparison of the measured values and values calculated by the Fluent CFD software is used for verification of the model. Four graphs show the course of velocity, temperature, CO_2 and NH_3 concentrations along the line where the measurements were taken.

Fig. 2 shows the velocities at two profiles. Measured and calculated values are in a good coincidence. The boundary velocities and pressures are adjusted correctly and the flow field corresponds with the shape of velocity profile in the actual broiler house.

Similar is the situation with temperatures (Fig. 3). The only difference is that the computed temperatures are a little bit higher than the measured ones. The reason probably consists in more intensive ventilation through the first two or three windows and maybe also in the

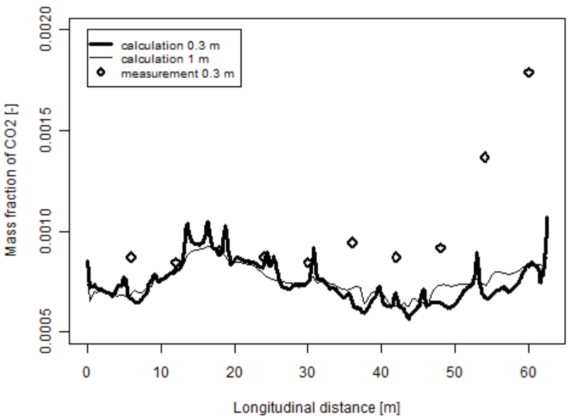

Fig. 4. The comparison of CO2 mass fraction profiles along the broiler house

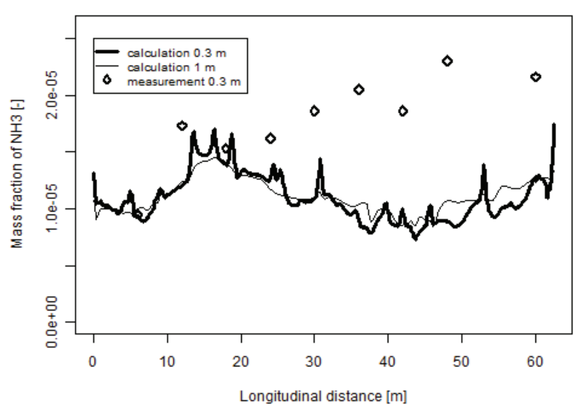

Fig. 5. The comparison of NH3 velocity profiles along the broiler house

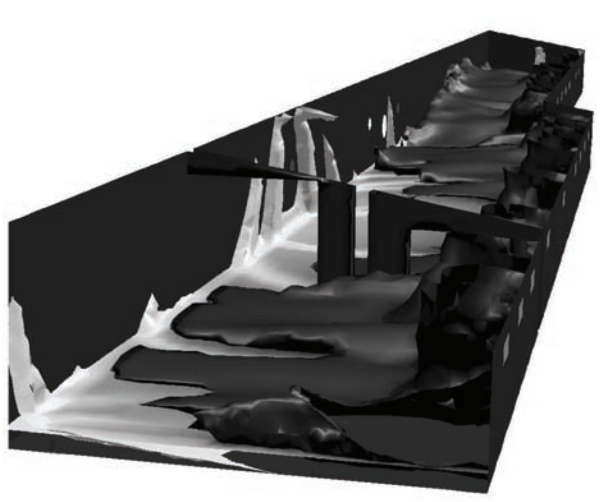

Fig. 6. Iso-surfaces of NH3 mass fraction value in cross ventilation. The dark one belongs to the mass fraction of 17 ppm

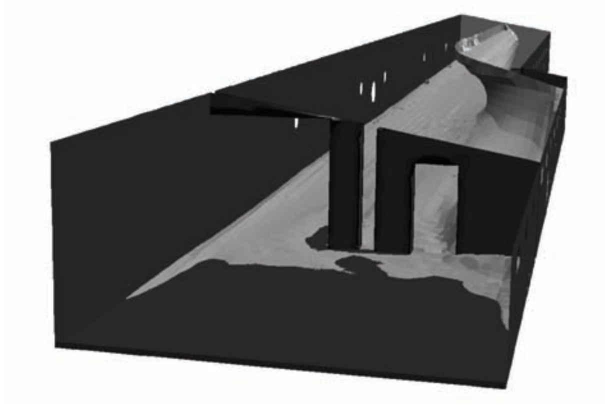

Fig. 7. Iso-surfaces of NH3 mass fraction value in longitudinal ventilation. The iso-surface belongs to the mass fraction of 23 ppm

fact that during the first hour of the measurement the temperature went up. All the temperature values were measured from the front of the hall towards the rear (from the left to the right in the graphs).

Interestingly, in Figs. 4 and 5, rightwards, a greater concentration of poultry at the back of the broiler house during the measurement is apparent. As the apparatus was moving, the chickens were plugged rearwards the hall and therefore the distribution of poultry over the hall was to a great extent irregular.

Finally, Fig. 6 shows the iso-surfaces of NH_3 concentrations. This picture shows the capability of the Fluent CFD software to present the 3D visualization of areas with low ventilation. On this picture, the dark cloud represents the iso-surface of constant mass fraction of NH_3 with the value of 17 ppm. The bright cloud belongs to the mass fraction of 20 ppm.

At the second part of the work the model was modified to show the changes of the flow character due to the longitudinal ventilation. The front, wider part of the hall was used as the input zone for fresh air and the back part was defined as the outlet. All other boundary conditions were leaved unchanged and the flow regimen was adjusted to respect the same flow rate, as was obtained during the simulation of transversal flow. Results of this simulation are shown in Figs. 7–11. The air flow is more smooth and also concentrations of chemical species are growing up smoothly as can be intuitively predicted – compare Figs. 6 and 7.

The air passing through the whole building from inlet to outlet increases concentration of pollutants. The highest concentration of CO_2 and NH_3 can be observed in the corner at the right end of the wider

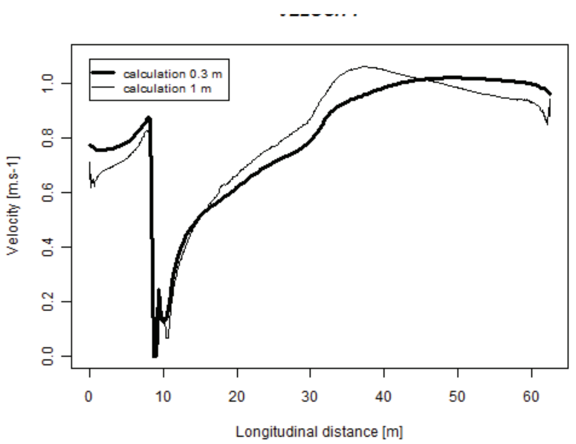

Fig. 8. Prediction of the velocity profile in the case of the longitudinal ventilation

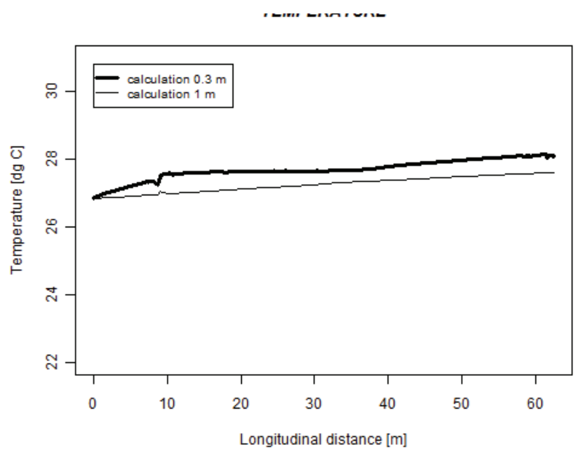

Fig. 9. Prediction of the temperature profile in the case of longitudinal ventilation

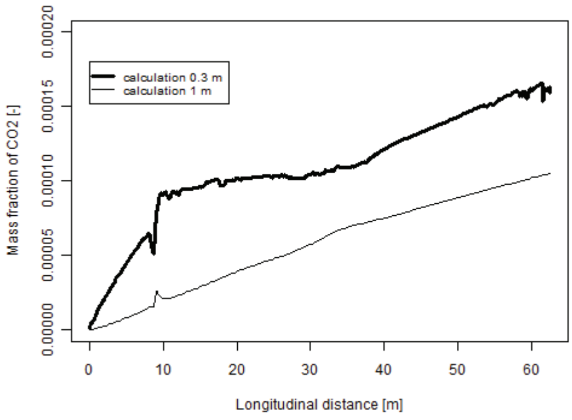

Fig. 10. Prediction of the mass fraction of CO_2 profile in the case of longitudinal ventilation

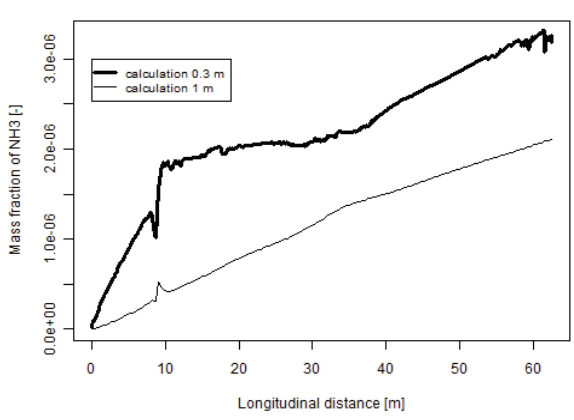

Fig. 11. Prediction of the mass fraction of NH_3 profile in the case of longitudinal ventilation

(front) part of the hall, where velocities are very slow and where a little recirculation flow can arise.

It is also shown that velocities at the measuring profiles are approximately three times higher than during the transversal flow. This is a fact which is very useful during the summer, when the ventilation has to be very intensive and the short residence time of air is needed.

DISCUSSION

Differences between the experimental data and the measured values are in some cases caused by factors, influencing the shape of the final numerical solution and also there are many errors which are projected into the measurement. The measurement depends on the quality and the precision of measurement conditions in the real buildings and also on the perfect geometrical adjustment of probes, which could be problematic.

The CFD model has a lot of simplifications which can also modify the results. In the present case it is mainly the neglecting of small air inputs in walls, as are for example leaks around the doors. The uniformity of thermal and species source is also a great simplification opposite to the fact, that poultry exactly represents hundreds of moving sources of heat and mass flow.

In spite of these problems and simplifications it is possible to make numerical model of a broiler house, which can be used as a very useful scientific toy. Now it is possible to easily change different boundary conditions and to prove their influence on the whole system.

The model with longitudinal flow shows realistic flow conditions which can be estimated in the case of reconstruction of the ventilation system and therefore the present information can be very useful for investors and the farm owners.

CONCLUSION

Tuning of the 3D model, which represents a relatively complex problem, is a very time-consuming work, but when finished, it can be used as a base line for many different kinds of simulations which would lead to higher understanding of properties of ventilated zones, and finally to the decision how to improve ventilation of the broiler house.

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