Agronomy Research Biosystem Engineering Special Issue 1, 235-242, 2012

Improvement of the broiler house ventilation using the CFD simulation

M. Zajicek[1] and P. Kic[2]

[1]Institute of Information Theory and Automation, The Academy of Science of The Czech Republic, v.v.i., Pod vodarenskou vezi 4, 182 00, Prague 5, Czech Republic; e-mail: zajicek@utia.cas.cz
[2]Czech University of Life Sciences Prague, Faculty of Engineering, Kamycka 129, 165 21, Prague 6, Czech Republic; e-mail: kic@tf.czu.cz

Abstract. The need for an exact control of the indoor conditions in buildings is the main reason for different simulation methods as a help for designers and researchers. This paper is focused on the numerical analysis of ventilation of building for broilers during the summer period with the use of computer fluid dynamics (CFD) software from Fluent Inc. The summer period is particularly critical. This paper presents the results of measurement and CFD analysis of the flow pattern, thermal state and concentration of pollutants inside the broiler house. Calculation respected the Czech standard. Final results show the improved arrangement of ventilation.
There are a lot of aspects which has to be included in the process of improving the function of an existing broiler house ventilation system. It is commonly required to find an acceptable balance between the financial costs and maximum obtainable functionality of the system. It is usually impossible to make great structural and interior changes for houses and therefore the geometrical shape and the configuration of inlets and outlets is almost definitely a given and non-changeable condition.
The paper presents the CFD solution of miscellaneously improved cases for the various flow and shape configurations of the broiler house. Effects of the transversal and longitudinal ventilation are combined with the changes of inlet air streams directions and also with the different cross-section shaping obtained using curtains.
All cases are evaluated and compared according to the same methodology. Results are discussed in terms of an existing state and also in terms of the expected costs needed for the ventilation system reconstruction.

Key word: broiler house, ventilation, fluid dynamics.

Introduction

The aim of this paper is a numerical analysis of the ventilation of the building for broilers during the summer period. Air flow rate in the animal's residence zone is one of the main parameters affecting the formation of a 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 a weight of several kilograms). The biological production and the thermoregulatory abilities of a 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 the loading of small day-old chicks. The basic problem solved by using the 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 the 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.

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 an undoubtedly wide range of applications relevant to the investigation using CFD (Gascone et al, 2006).

The reason for the use of numerical analysis is driven in most cases by a need of a detailed understanding of the flow pattern in a ventilated area and often with the possibility of simulation of emergency situations. This work is the next step in the analysis of the applicability of FLUENT for such kinds of problems (Kic & Zajicek, 2009) and (Kic & Zajicek, 2010).

The numerical analysis of a 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.

Materials and methods

The basic assumption of this research is to perform measurements in an existing broiler house. Exterior of the building is shown at Fig. 1. It has to be mentioned that this building isn't a typical broiler house, because it is relatively long (62 m) and has a changing cross-section area along the longitudinal direction. Results obtained during the measurement and the method of creating the computational model which corresponds to the real state has already been published (Kic & Zajicek, 2011). The typical numerical result compared with measured data is shown at Fig. 2. The difference between measured values and calculation on the right side is caused by the higher concentration of poultry in the right part of object during the measurement, while the numeric calculation assumes the homogenous production of pollutants.

Fig. 1. The broiler house used for the analysis.

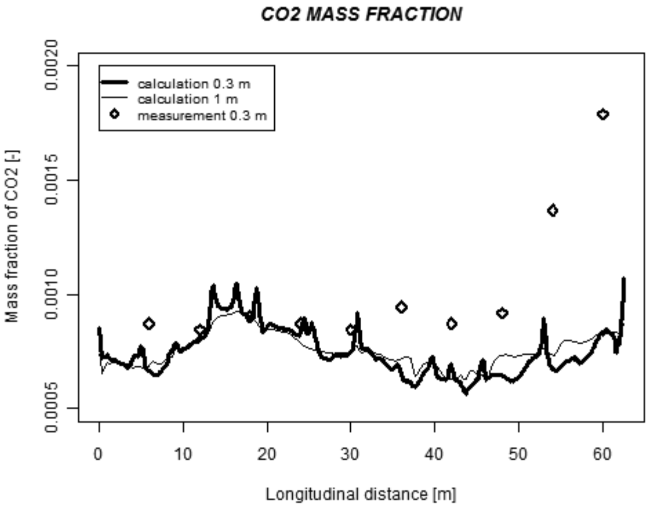


Fig. 2. Typical comparison of measured and calculated values obtained during the tuning of a numerical model.

This article is focused on the solving of shape variants and their influence on the overall flow patterns. The barriers used for modification of the cross-section shape of the house can be realized using the curtains or blinds from suitable material. Fig. 3 shows the geometrical representation of such barriers and their position along the hall and also the detailed shape of the numerical model in the front corner of the broiler house for one of the variants. Rectangular zones represent areas, where the inlets (or outlets) can be defined. They give the possibility to simulate a number of flow regimes for each geometrical configuration of barriers.

The computational model in this case has about 300,000 cells and the front and rear wall is provided with the inputs and outputs for simulating the case of longitudinal ventilation, which is not possible in existing building yet.

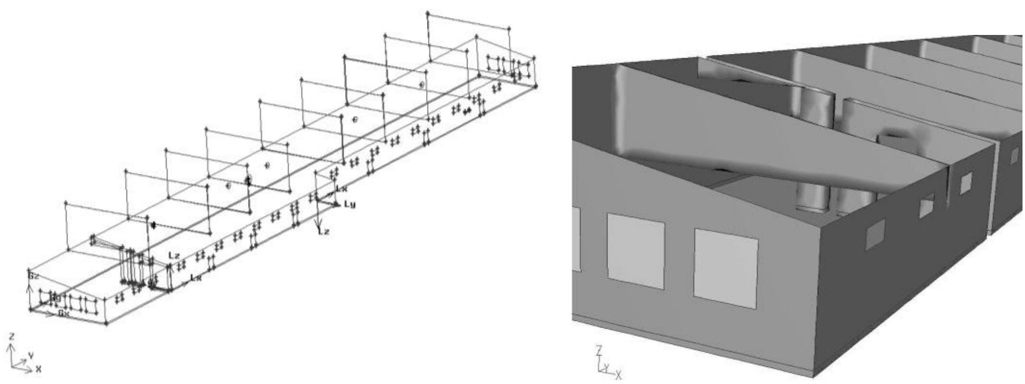


Fig. 3. Geometrical model with curtains prepared for making the decided configuration and a detail of the computational model used for simulation.

There are three geometrical variants Z, A, B presented here and four flow regimes are solved for each of them.

- Z – variant ‘Zero’ is the basic variant without barriers which geometrically responded to the existing state without any barriers.
- A – variant has all barriers pulled down. The distance from the floor to their bottom is 1.4 m.
- B – only barriers in the front (wider) part of the broiler house are pulled down to obtain the same cross-section area in both parts of the interior. The distance of lowered barriers from the floor is 2.1 m in this case.

All basic variants (marked with a letter A, B, Z) are complemented with the same set of different boundary conditions corresponding to different flow regimes and then solved using Fluent Inc. software. Boundary conditions (BC) are marked with numbers and the sides, directions and orientations are explained according to the Fig. 3:

- BC set no. 1: The same inlets and outlets configuration as was observed during a measurement is simulated. Windows no. 5, 7, 18 and 21 are closed and only ventilators no. 1, 4, 5 and 6 are switched on. Inlets and outlets at long sides are numbered in sequence from left to right;
- BC set no. 2: All windows and all ventilators are used for the transversal ventilation;
- BC set no. 3: Longitudinal ventilation with three ventilators at the right end of the building and four inlets at the left. The flow direction is from left to right;
- BC set no. 4: Longitudinal ventilation with four ventilators at the left end of the building and three inlets at the right. The flow direction is from right to left.

Thus the Z1 case is the variant completely corresponding with the existing state. The constant total flow rate 2.5 $m^3 s^{-1}$ is adjusted in all 12 solved cases and is symmetrically divided between all active ventilators in every case.

Results and discussion

The main objective of this article is to show the attempt which can be used for determining the appropriate configuration of geometrical and flow conditions, which can lead to the optimally ventilated broiler house with respect to the welfare of chickens. The greatest problem is to say which combination of criterions can be used as a measure of such ‘optimality’.

Using CFD provides a great possibility to obtain a large amount of data sets, which corresponds to the individual cases. A comparison of velocity profiles, temperature profiles, pollutant concentration profiles and others can be done. The visual comparison of the flow field can also be very useful. Fig. 4 shows the particle tracks of air for the case A3. The existence of two different flow regions is clearly visible. There is a bottom region with the straight and quick flow under the barriers and the upper part between barriers where the massive circulation can be seen, and where the slow velocities and long residence times can be expected.

Fig. 4. Pathlines of air obtained during the simulation of longitudinal ventilation.

The main results of the presented simulation is summarised in Figs. 5–7, where the velocity profile, temperature profile and profile of CO_2 concentrations are shown. It is important that all simulations are made for the same flow rate and they are therefore visually comparable according to the same scale. For example: Comparison of the velocity profile of A3 and B3 cases shows the more uniform profile in the case B3, which can be assumed due to the same cross-section areas in both parts of the broiler house.

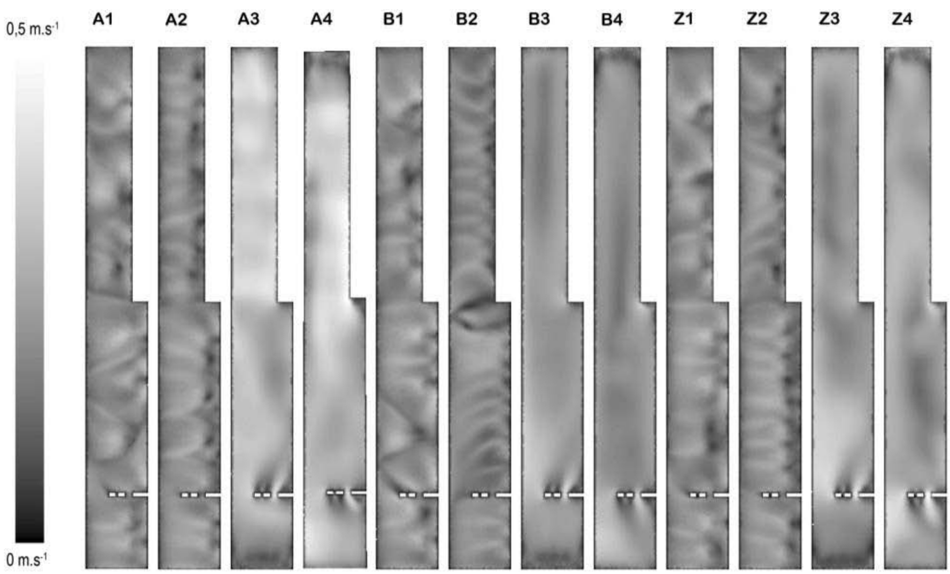


Fig. 5. Comparison of air velocity profiles at a level of 30 cm above the floor.

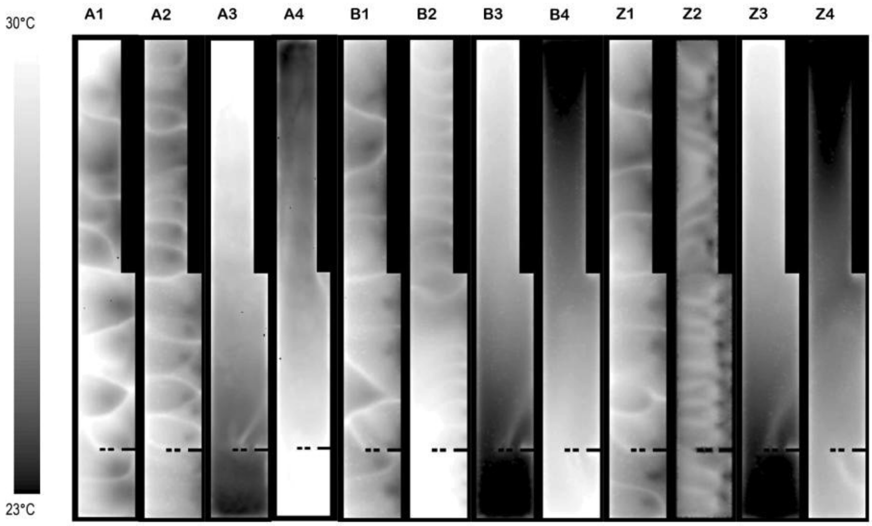


Fig. 6. Comparison of air temperature profiles at a level of 30 cm above the floor.

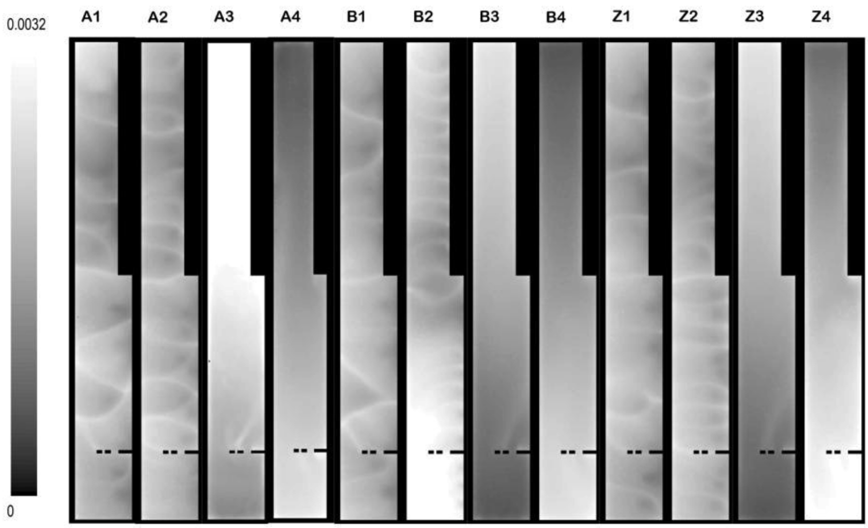
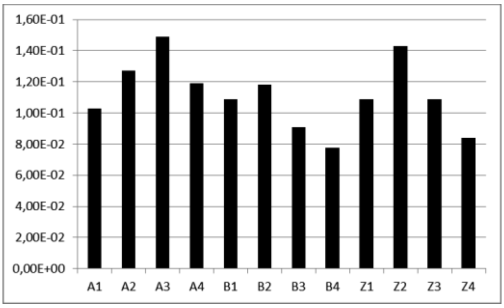


Fig. 7. Comparison of CO_2 mass fraction profiles at a level of 30 cm above the floor.

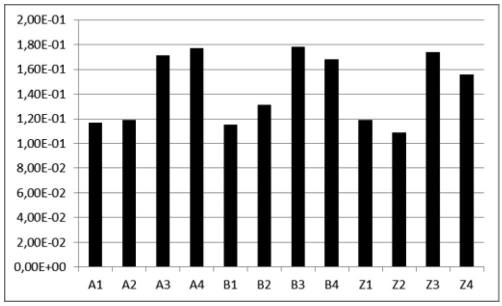
From a theoretical point of view, statistical methods can be used to make a decision about the quality of each solved case (Pus, 2011). Evaluation of statistical descriptive characteristics is made from the set of values which are obtained from the plane, 0.3 m above the floor. It is the plane where the chickens head position can be expected. All node values of velocities, temperatures, concentrations and other values are exported as a Fluent profile (file with ordered coordinates and property values). Every profile is then imported into the author's own program written in FORTRAN, which analyses input data and calculates basic statistical descriptive characteristics of every individual case (mean value, range, standard deviation, dispersion …). Fig.8 shows the value of Student's standardisation.

$$t_S = \frac{\sum_i \left| X_i - \bar{X} \right|}{X_{\max} - X_{\min}} \tag{1}$$

It can be used as a rate of non-homogeneity of given set of values. The higher values of this number means that the homogeneity of a given set of data is poor (there is a lot of values far from the mean value).



Air velocity profile standardisation



Air temperature profile standardisation

Fig. 8. The Student's standardisation criterion for the air velocity and temperature profiles obtained for individual simulations.

It is clear that a wide amount of statistical characteristics can be obtained and it is always important to make a decision about which of them has a sense to be used and why.

The economical point of view is very important for investors, who like to upgrade or rebuild existing facilities. It is clear that the expenses of installing new technology can vary. It has to be mentioned that the costs of an expensive HVAC (Heating, Ventilation and Air Conditioning) technology can be in many cases reduced by using less sophisticated, but effective attempts, like a changed position of air inlets, shaping the flow pattern with varying directions of input and output stream. The CFD simulation looks to be the right tool to help with making such a decision more responsibly.

Conclusions

Design, installation and also the production of equipment for HVAC is often based on numerical simulation. The attempt shown here is very time consuming for making a complete analysis of tens of individual cases. However it is very useful when there is a need to compare a few variants or decide which computational variant is important for future improvement or research interests. It is also observed that numerical CFD analysis can be successfully used as a starting point for statistical analysis or boundary conditions for other analysis.

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