Comparison of airflow homogeneity in Compost Dairy Barns with different ventilation systems using the CFD model

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In the pursuit of high milk productivity, producers are using confinement systems in order to improve performance and animal welfare. Among the housing systems, the Compost bedded-pack barns (CBP) stand out. In these barns a bedding area is provided inside, where cows move freely. The ventilation in these facilities has the function of dehumidifying the air, improving the air quality, drying the bedding, improving the thermal comfort conditions of the confined animals. This work aimed at validating a computational model using Computational Fluid Dynamics (CFD) to determine the best homogeneity of airflows generated by different forced ventilation systems used in CBP barns.

Materials and Methods

The experimental study was carried out in two CBP systems during the months of September and October 2018. One of the dairy farm was located in the Sete Lagoas, Minas Gerais, Brazil (CBP_{LVHS}). The other animal facility was located in the Piracicaba, São Paulo, Brazil (CBP_{HVLS}). The evaluated CBP barns had dimensions of 20.0 m wide x 80.0 m long x 5.0 m side height. Both CBP barns had different ventilation systems and open sides. One CBP barn had six High Volume Low Speed (HVLS) fans, placed horizontally, with a diameter of 7.3 m, speed of 50 rpm, power of 2.0 hp and a flow rate of 478,500 $m^3\ h^{-1}$ each. The HVLS fans were distributed along the length of the CBP barn at a distance of 12.0 m at a height of 3.0 m. The other CBP barn had twenty Low Volume High Speed (LVHS) fans, with a diameter of 2.0 m, rotation of 360 rpm, a power of 3.0 hp and a flow rate of 120,000 $m^3\ h^{-1}$ each. The LVHS fans were distributed, in pairs, along the length of the CBP barn at a distance of 8.0 m at a height of 3.0 m.

For the test and validation of the computational model, dry bulb temperature (T_{db}), relative humidity (RH), air speed and direction (V_{air}) and bed surface temperature (T_{bed}) data at two-second intervals, for two days consecutive at each CBP barn, were collected. The data were collected at 27 distributed points, in a 3 x 9 equidistant grid along the compost pack resting area at 0.50 m high.

The definition of the domain geometry represents the first stage of the simulation in CFD. Domain geometry for this study was generated with the software SolidWorks®. The simulations were carried out by means of software ANSYS® version 17 (available at the Federal University of Rio Grande do Sul, Mechanical Engineering).

Due to the complexity of the geometry and the dimensions of the fans, we chose to use the software ANSYS ICEM CFD® for designing a computational mesh with tetrahedral cells. Tests with different mesh sizes were conducted until there were no significant differences between measured and simulated data (p <0.05). As a result, a mesh of 3,805,719 tetrahedral elements (Fig. 1) was designed and used as the computational domain.

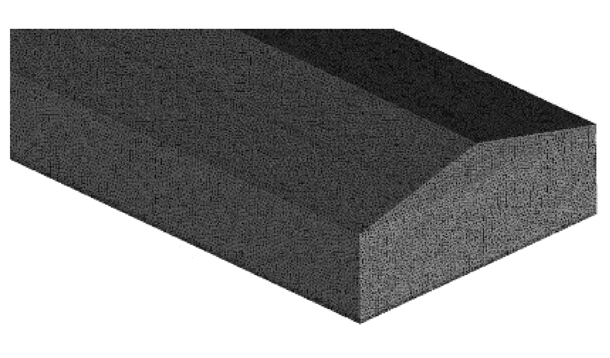

Figure 1. Mesh generated for implementation of the CFD model.

In this study the solution of the Reynolds number average system extracted from the Navier – Stokes equations allowed to define the CFD technique. The purpose of the CFD simulations was to carry out an evaluation of the flow homogeneity, that is, to verify the flow behaviour and its distribution in the compost pack resting area. In simulations ANSYS CFx software was used assuming four conditions (a: steady state; b: single-phase flow; c: thermal energy condition; d: incompressible and turbulent flow). The simulated solution was validated using experimental data. The mean residue for linear systems technique (RMS, Root Mean Square) was considered with a tolerance of 10^{-4} as convergence criterion and a limit of 100 interactions.

Results

The relationship between air velocity data coming from experimental tests and from the model is illustrated in Fig. 2.

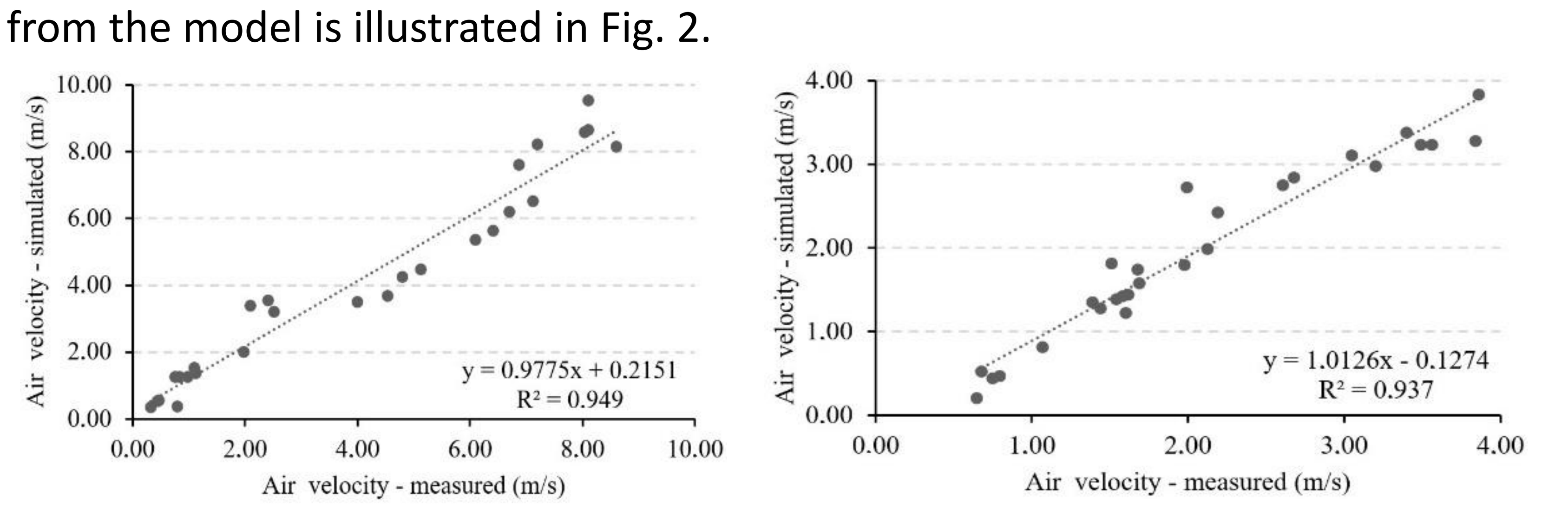

Figure 2. Relationship between model and experiment data for air velocity in CB barns with different ventilation systems: a) LVHS and b) HVLS.

The airflow lines and velocity distribution on the surface of compost pack resting area in the modelled CBP_{LVHS} barn can see in Fig. 3. The results demonstrate the current air flow lines for the HVLS fan (Fig. 3a) that may undergo small variations. These variations are of small magnitude and do not significantly affect the results. The current air flow lines, through an HVLS fan, coming from the fan, close to the bed surface, is oriented in all directions. Below each fan, specifically in the centre, is a region of lower speeds (Fig. 3b).

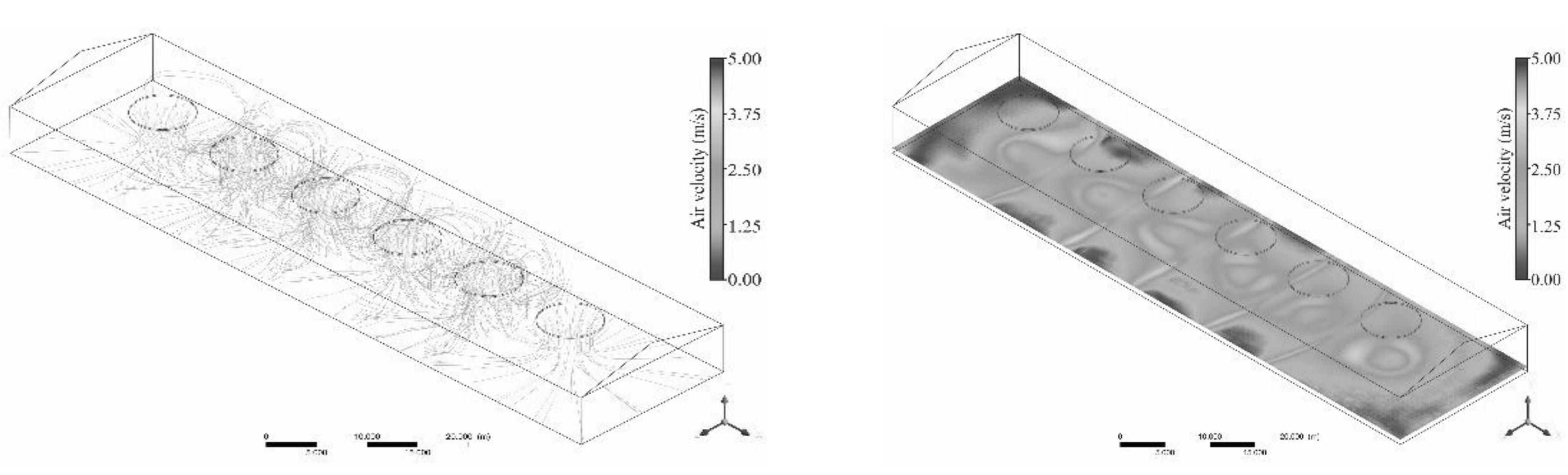

Figure 3. Results of CFD simulation of CBP barns with HVLS ventilation system: a) air flow lines and b) air velocity distribution on the surface of compost pack resting area.

The result of the CFD simulation in the CBP barn with the LVHS ventilation system is shown in Fig. 4. The air flow created by LVHS fans is distributed close to the surface of the compost bed, following the longitudinal direction of the barn (Fig. 4a). Fig. 4b shows the distribution of air velocity on the bed surface. At one end of the bedding area the air velocity values are very low. Two regions are observed at the opposite end of the CBP facility with higher speeds in the centre (around 4.0 m s^{-1}) and lower ones on the sides (around 2.5 m s^{-1}) of the compost bedding area.

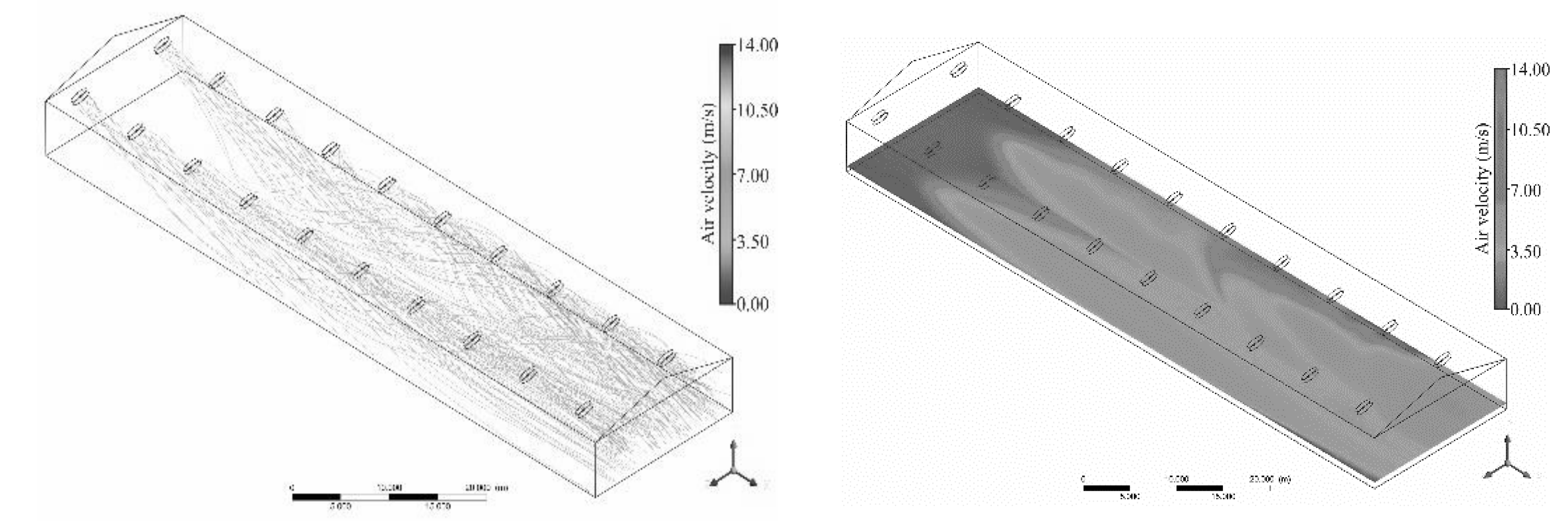

Figure 4. Results of CFD simulation of CBP barns with LVHS system: a) air flow lines and b) air velocity distribution on the surface of compost pack resting area.

Conclusions

The model was validated and could be used to predict the behavior in real time of air velocity distribution inside the CBP barns with differents ventilations systems. The comparative analysis of the air flows generated by the HVLS and LVHS fans showed visual information that allows the evaluation to determine the best air flow homogeneity. The results indicate a better homogeneity in the CBP barn with HVLS fans with a smaller area with speed close to zero. In all CBP barns evaluated, the air velocity (V_{air}) was higher than the recommended (1.8 m s^{-1}) in most of the bedding area, so that it can dry the bed, remove gases and favour the heat exchanges between the animal and the environment. Nevertheless, in future studies, CFD models could be used to predict the distribution of heat within the CBP barns at different air speed and types of ventilations systems.

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