AIRFLOW PATTERN AND CONTAMINANT DISTRIBUTION IN SWINE BARN

EFFECT OF VENTILATION SYSTEM DESIGN ON THE AIRFLOW PATTERN AND CONTAMINANT DISTRIBUTION IN A SWINE BUILDING

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Summary

Proper distribution of air in a ventilated barn is important in order to achieve satisfactory temperature and air quality in a swine barn. To design an effective contaminant control system in a conventional-flow type of swine barn, an understanding of airflow is most important. In this project, the FLUENT computer model was used to simulate the airflow pattern and ammonia concentration in a grower-finisher room. The predicted airflow was a three-dimensional pattern. The three-dimensional flow structure, the contaminant concentration and temperature at the human breathing line (1.6 m above the floor) were highly affected by the combined jets which were composed of a ceiling inlet jet and a recirculation slot jet. The placement of the ceiling inlet and the recirculation duct affected airflow patterns, but had only a slight effect on the distribution of velocity, temperature and ammonia concentration along the human breathing line. Increasing the flow rate of cleaned recirculation airflow resulted in a lower ammonia contaminant level along the human breathing line. However, higher flow rates of cleaned recirculation air meant there would be higher fan operation and air cleaning costs. The optimum ratio of the ventilation rate to the cleaned recirculation rate appeared to be approximately 1:4.

Introduction

Several factors influence airflow pattern and contaminant transport in mechanically ventilated livestock buildings. These include the configuration of the ventilation system, ventilation rate, the location and structure of air inlets, the conditions of the incoming air, building size and shape, enclosure design, and heat and moisture production by the animals (Randall, 1975). These factors may also affect the contaminant transport inside the building. The contaminant transport is also affected by the generation rate of contaminants and the location of the contaminant sources.

Previous studies have focused on the simulation and experimental investigation of the airflow pattern and contaminant concentration distribution in a two-dimensional airspace (Nielsen et al., 1979; Timmons et al., 1984; Choi et al., 1992; Krause and Janssen, 1990; Maghirang et al. 1992; Zhang et al., 1992). These studies tried to simulate the ventilated space with a continuous slot (opening in ductwork) located at one side wall, and the exhaust fans installed on the opposite side wall. Due to the limited number of exhaust fans used, the three dimensional effects on the flow pattern and contaminant distribution were not accounted for in such two-dimensional studies. Few studies considering a three-dimensional airflow pattern and contaminant distribution in a livestock building have also been conducted (Hoff et al., 1993; Harral and Boon, 1993; Christensen, 1993). However, these three-dimensional studies only investigated the flow pattern and contaminant distribution in an empty room with only fresh air diffusers (vent covers with fins for diffusing air). The effect of a recirculation air system on the flow pattern was not considered then.

In the present project, the FLUENT CFD model was used to determine the effect of the ceiling inlets and the design of the recirculation system on the pattern of airflow in a grower-finisher room fitted with a ventilation system using discontinuous ceiling inlets combined with discontinuous recirculation-assisted slots. The effects of the placement of slots and the filtered recirculation airflow rate on the airflow field and the contaminant distribution were also investigated.

Building description

The floor plan of the swine barn is shown in Figure 1. This facility represented the full-scale grower finisher room (Engineering Room) at Prairie Swine Centre. The interior dimensions of this room are 14.3 m x 11.0 m x 3.0 m. It has 12 pens, 6 on each side of a middle alley connected with a door to a side corridor.

Twelve ceiling-inlets (MacKay MGM Air Inlet) were installed above the inspection alley in two rows. The distance between the exit side of two row inlets was 1.6 m. The inlet dampers were hung at ceiling level
on the alley side, directing the fresh air by an attached jet toward the side walls. Two recirculation ducts were hung under the ceiling inlet. The recirculation air was sucked in by a fan installed at one end of each recirculation duct. The air was discharged through the discontinuous slots opened at the side wall of the duct. The discharged recirculation air traveled parallel to the ceiling surface and toward the side wall of the room.

A negative pressure ventilation system was used in the test room. Four exhaust fans were installed in an end wall opposite the door. Winter ventilation was provided only by a variable speed fan (Del-Air J-16). Fully slatted floors were made of concrete elements with module dimensions 53 cm by 122 cm. The porosity of the slatted floor is approximately 20%. The manure pits are 122 cm wide and 61 cm deep.

Numerical model

For the present project, the chilled air entered the warm room through the ceiling inlet. The flow was largely affected by buoyancy forces and the flow also was affected by the behavior of the combined jets. The turbulence model used in this project was the k-ε model. The model includes buoyancy effects caused by temperature difference, not only on the mean momentum equation in the vertical direction, but also on the equations of turbulent kinetic energy and kinetic energy dissipation.

FLUENT solves the governing partial differential equations for the conservation of mass, momentum, energy, contaminant and turbulent characteristics k and ε in a general form as:

\[
\frac{\partial \rho \mathbf{U}}{\partial x_i} = \frac{\partial}{\partial x_i} \left[ \Gamma_k \frac{\partial \phi}{\partial x_i} \right]
\]

Results and Discussion

Airflow pattern is very important to air distribution in a room. The inlet location and the conditions at the inlet can affect the airflow pattern significantly. In the present study, fresh air flowed into the building through the discontinuous ceiling inlets, and recirculation air flowed into the air space through the recirculation slot just under each ceiling inlet. Two air jets flowed horizontally toward the side wall. At some locations, the two jets merged into one air flow stream. The combined jet provided momentum to the other airspace and formed a large rotary flow region just under the jet region. The behavior of the combined jets can affect the airflow pattern and other variable distributions across the entire air space of the room.

Figure 2 presents the profile of the velocity component in the z-direction at the middle cross section of pen No. 10 (Figure 1). The figure clearly shows how two jets develop along the jet region and combined into one final jet. At location 2, there is only one recirculation jet. At location 3, the ceiling air jet flows into the room through the ceiling inlet. There is a low velocity profile region between two peak velocity points. Two jets start to expand from
where they originally entered the air space. At locations 4 and 5, the two jets expand along their flow direction and start to merge. At location 6, the two jets are completely merged together and its behavior is as a single jet. However, such combined jet behavior still depends on the behavior of the two original air jets.

**Figure 2** Velocity profile at the middle of the cross section of pen No. 10  
(Velocity range = -0.58-2.66 m/s)

**Effect of different flow rate ratios**

Figure 3 represents the airflow patterns for two cases across the x-z planes (y=1.5 m). The figure shows that the different combination of the ventilation and the recirculation rate can affect the airflow pattern in the room significantly. For case A (Figure 3a), there were three rotary flow zones, while case B (Figure 3b), had two rotary flow regions. These two regions were symmetric along the middle section of the room.

Further investigation showed that increasing the ventilation rate resulted in decreased ammonia concentration in the airspace of the swine building, while increasing the recirculation rate did not affect the ammonia concentration in the swine building.

a) Case a (Velocity range = 0~0.75 m/s)  
\[ Q_V = 0.25 \text{ kg/s and } Q_R = 0.9 \text{ kg/s} \]

b) Case b (Velocity range = 0~0.52 m/s)  
\[ Q_V = 0.25 \text{ kg/s and } Q_R = 0.45 \text{ kg/s} \]

**Effect of slots placement**

Several factors can affect the airflow patterns in swine buildings. One of the most important factors is the location of the inlets. In a cold climate, a recirculation system is often used to distribute air. Different arrangements of air inlets and recirculation air systems would result in different airflow patterns. In this subsection, the effect of slot placement on the airflow pattern and contaminant was investigated. Three different arrangements of inlets and recirculation slots were considered (Figure 4).
Figure 4 Arrangement of slot inlets

Figure 5 presents the airflow patterns at the middle of the cross section of pen No. 10 for three different arrangements. Due to the deflection of air through the recirculation duct, the flow patterns near the ceiling surface for arrangement 3 were quite different from those for arrangements 1 and 2. There were two flow zones for arrangement 3. The zone at the left side of the recirculation duct had a higher rotation strength than that of the zone at the right side of the recirculation duct. This was due to the two air jets initially discharged into the left side flow zone. The flow patterns for arrangement 1 are similar to that of arrangement 2. However, the center of the rotary zones were different.
Figure 6 represents the profile of ammonia concentration along the human breathing line (approximately 1.5 m from the floor surface) for the three different arrangements of the ceiling inlet and the recirculation duct. The figure shows the placement of the inlet and the recirculation duct has a slight effect on the distribution of ammonia concentration along the breathing line.

Figure 6 Effect of arrangement on the ammonia concentration along breathing line

Effect of flow rate of cleaned recirculation air

Figure 7 shows the ammonia profiles along the human breathing line at the middle cross section of pen No. 10 for a different combination of ventilation rates and cleaned recirculation airflow rates. Three different combinations of ventilation and recirculation rates were used. The concentration of ammonia at the recirculation slot was 37 ppm for uncleaned recirculation air, and zero for cleaned recirculation air. Figure 7 indicates that cleaned recirculation air dramatically decreases the air contaminant along the human breathing line. The figure also shows that a higher flow rate of cleaned recirculation air results in a lower ammonia contaminant level along the human breathing line. However, increasing the flow rate ratio above 3.6 did not decrease the contaminant significantly. A higher cleaned recirculation rate caused a higher recirculation fan operation cost and air cleaning cost.

Figure 7 Effect of the placement of inlet slots on the ammonia contaminate distribution along the human breathing line.

Conclusions

The main purpose of this project was to numerically study the effect of the ventilation system design on the flow pattern and the contaminant distribution. The following conclusions were drawn based on the results presented here:

The predicted velocity profiles showed that after traveling a certain distance, the fresh air jet and recirculation air jet could be assumed as a single combined jet which behaved similar to a single air jet.

Different combinations of ventilation rate and recirculation rate affected the airflow pattern and other contaminant distributions along the human breathing line. Increased ventilation rates resulted in decreased ammonia concentration in the air space of the swine barn, while the recirculation airflow rate had no effect on the ammonia concentration.

The placement of the ceiling inlet and the recirculation duct had no significant effect on the profile of the ammonia concentration along the human breathing line, but did affect the airflow pattern.

Increasing the flow rate of the cleaned recirculation air resulted in decreased ammonia concentration along the human breathing line. The optimum flow ratio of ventilation rate to the cleaned recirculation air rate was about 1:4.
References


