Ventilation System Requirements for Converted Gestation Barns

B. Predicala, A. Alvarado, and R. Baah

Bernardo Predicala

Alvin Alvarado

SUMMARY

Computer simulation was utilized to assess the performance of different ventilation system configurations needed for a sow gestation barn newly-converted to group housing. Various configurations of the ventilation system involving varying capacities and locations of exhaust fans as well as size, design and location of air inlets, were examined based on indoor air quality (i.e., air temperature, humidity, and air speed at the animal level) and ventilation effectiveness (i.e., air distribution and airflow pattern, inlet air velocity, and room static pressure). Based on the computer simulation results, horizontal flow ventilation system with air inlets on one side and exhaust fans on the opposite side showed the best simulated performance among all ventilation design configurations tested. The horizontal flow ventilation configuration was then selected for further evaluation in an actual group sow housing facility, where energy use, temperature and air quality, and sow welfare and performance were assessed.

"Among all the design configurations tested, horizontal flow ventilation system was the most effective in removing heat from the animal occupied zone."

INTRODUCTION

Ventilation affects many aspects of the animal environment as well as barn operating costs, specifically energy costs. Retaining the existing ventilation system in a converted group-housed sow barn leads to over-ventilation during winter because the existing minimum ventilation fans are designed for higher animal density, thereby using extra heating fuel, and most likely causing chilling of the animals and affecting its performance. According to Harmon et al. (2010), if ventilation is continued at the pre-remodeling level (prior to conversion to group housing), the building would be over-ventilated by about 33% higher than required.

An estimate of energy use for an over-ventilated facility indicated that over-ventilating by 30% can raise heating energy consumption by 75%. During summer, the impacts are less pronounced but over-ventilation will use extra electricity which translates to higher electricity cost (Harmon, 2013). In addition, the transitioning of the ventilation system design from stalls to group housing is not simply reducing the ventilation rate but requires careful reconfiguration to ensure proper air distribution throughout the room to eliminate dead spots (unventilated areas) and unwanted drafts.

Air exchange is critical to providing a healthy environment that fosters efficient pig growth by reducing humidity and noxious gases like ammonia and carbon dioxide. Since under-ventilation creates an unhealthy environment and over-ventilation wastes valuable heating and electrical energy, finding the right balance is the key to a healthy environment for both animals and workers as well as to energy savings and efficiency (Harmon et al., 2010). This balance can only be achieved by careful re-design of the existing ventilation system of a converted gestation barn.

MATERIALS AND METHODS

Assessment of ventilation system designs using computer simulation

In this project, numerical computer simulation technique which utilized computational fluid dynamics (CFD) principles to numerically simulate fluid flow, heat and mass transfer, and mechanical movement, was used as a tool to examine various design configurations and determine the most effective design of the ventilation system for a converted group sow housing facility.

The ventilation system design parameters investigated include: (1). capacity and location of exhaust fans, and (2). size and location of air inlets. These two parameters were configured in such a way that the resulting ventilation system design followed the principles of either an upward airflow, downward airflow, or horizontal flow ventilation.

Computer simulation was carried out using ANSYS Fluent 15.0 (ANSYS Inc., Canonsburg, PA, USA). The setting-up of models and mesh as well as the evaluation of results were done through the application of DesignModeler, Meshing and CFD-Post in the ANSYS Academic Research CFD Package (ANSYS Inc., Canonsburg, PA, USA). A standard κ-ε model with scalable wall functions was used. A pressure-based solver with SIMPLE algorithm was employed for the calculations

Barn implementation of the most effective ventilation system design

Two group-housed gestation rooms were used: one room designated as the Treatment room was modified to incorporate the horizontal flow configuration identified from the simulation work, while the second room's ventilation system was similar to those in pre-converted (stall) gestation barns (Control room).

A

B

Figure 1. Photos of the control room with the existing (unmodified) ventilation system (A) and the treatment room with the air inlets on the opposite side (B) following the principle of a horizontal flow ventilation system. B – inset: wall air inlets installed in the treatment room.

Figure 1 shows the ventilation design configuration of the two experimental rooms. In the Treatment room, air inlets are located on one side of the room and exhaust fans are on the opposite side allowing air to flow horizontally through the entire length of the room (Figure 1b). In the Control room, inlets are located on the ceiling while the fans are on one of the external walls; this configuration represents a downward air flow direction which is typical in commercial sow barns (Figure 1a). Each room has inside dimension of 23.1 ft (w) x 65 ft (l), two electronic sow feeders, four nipple drinkers, and housed 40 sows, on average, throughout the study.

With the exception of the ventilation system design, the management of the two rooms was as identical as possible throughout the test. Prior to the start of the trial sow feeder, sensors and monitoring equipment were all calibrated, and all sows were trained to use the sow feeders. Feed consumption of sows in the rooms were monitored in addition to daily health checks and all sows were weighed at the start and end of the trial.

RESULTS AND DISCUSSIONS

Computer models of the sow gestation rooms with different geometries were generated in the simulation work. The developed models were used in simulations under winter and summer conditions. In general, with the group housing layout and new ventilation design, heat removal effectiveness (HRE) values increased particularly when the air inlets were located on the opposite side of the exhaust fans following the principle of a horizontal flow ventilation system (HFVS). HFVS had an average HRE value of 1.32 ± 0.32, which was the highest among all the design configurations investigated. Also, for this configuration, all nine monitoring points in the animal-occupied zone (AOZ) had HRE values greater than 1 (lowest HRE was 1.08) which indicate that the air was homogeneously mixed.

During winter period, all HRE values decreased which could be attributed mainly to the lower ventilation rates maintained in the rooms during the cold season. However, HFVS still had HRE values greater than 1 in all 9 monitoring points. On average, HFVS had an HRE value of 1.11 ± 0.12, which was the highest among all the designs tested for winter. Therefore, this ventilation system configuration (horizontal flow ventilation system) was selected for the subsequent in-barn evaluation.

Temperature

Average air temperatures in both the control and treatment rooms were uniformly distributed ranging from 19.9-20.7°C and 19.3-20.8°C, respectively (Table 1). Set-point temperature in these rooms was set at 16.5°C which is the typical set-point temperature in actual gestation barns. On average, there was not much difference with the inlet air temperature for control (16.0°C) and treatment (16.1°C) rooms. However, significant difference was observed at the exhaust with the average air temperature of 19.9°C and 20.4°C for the control and treatment rooms, respectively. This may imply that the ventilation system in the treatment room is effective in removing heat from the room as compared to the control room.

The control room had an average HRE value of 0.92 ± 0.05 which generally implies that part of the fresh air coming from the inlets was directly removed from the room without mixing and without causing air displacement in the AOZ. This may result in accumulation of high contaminant levels at the AOZ because stale air is not being efficiently removed by the ventilation system. Only one point (at the center of the control room) had a HRE value of 1.0. Conversely, the treatment room had an average HRE value of 1.12 ± 0.15 indicating effective air displacement in the AOZ. Almost all the monitoring points in the treatment room had HRE values greater than one indicating that the fresh inlet air mixed well with the room air first before heading out through the exhaust.

Air quality

The treatment room had an average CO_2 concentration of 1343 ppm and ranged from 1238 to 1385 ppm. These levels were significantly lower ($p<0.05$) than the CO_2 levels in the control room which had an average of 1594 ppm and ranged from 1521 to 1654 ppm. Furthermore, the treatment room had an average CO2 concentration of 1359 ppm at the exhaust and 379 ppm at the inlet. The control room, however, had 1471 ppm at the exhaust and 538 ppm at the inlet. This implies that CO_2 was efficiently removed from the treatment room as compared to the control room, which is consistent with the HRE values calculated in both rooms.

Energy Consumption

Natural gas consumed for heating and the electricity consumed by the fans, room heater and lights comprised the energy consumption of the room. During winter, the treatment room with the horizontal flow ventilation consumed, on average, 608.7 m^3 of natural gas over four weeks for heating; this was about 21% lower than the control room which averaged 767.2 m^3. Similarly, average electrical consumption in the treatment room over four trials was, on average, 250 kWh while the control room averaged 250 kWh over the same period. The considerable difference in total energy consumption (natural gas and electricity) between the two rooms during the winter season was mainly due to frequency of heater operation; heater ran more often in the control room compared to the treatment room. During the summer months the difference in electrical consumption can be attributed to the operation of fans which is dependant on te temperature maintained in the rooms throughout the trial. It was observed the temperature in the treatment room was lower, but still within the recommended ramge, than the control room.

Location		Control		Treatment	
		°C	HRE	°C	HRE
Near door	1	20.1	0.93	19.3	1.10
	8	20.2	0.95	19.3	1.34
Middle of room	2	20.0	0.83	19.5	1.13
	7	20.7	0.91	19.9	1.26
	9	19.9	1.00	20.3	1.02
	3	20.3	0.91	20.0	1.26
	6	20.3	0.97	19.5	1.10
Near exhaust	4	20.5	0.93	20.8	0.93
	5	20.2	0.87	20.7	0.91

Table 1. Average air temperature and ventilation effectiveness at nine locations control and treatment rooms.

Sow performance and condition

Monitoring of the performance of sows in terms of rectal temperature, average daily gain (ADG), backfat depth, condition score and dirtiness over four trials showed that the average rectal temperature of sows in the control and treatment rooms was the same (36.7 °C). Moreover, no considerable difference was observed in ADG of sows in the control and treatment rooms which translated to similar condition score. Sow condition score was assessed using a 1 to 5 condition score with 1 – emaciated; 2 – thin; 3 – ideal; 4 – fat; and 5 – overly fat. Both rooms had an average sow condition score of 3 which is the ideal condition for gestating sows. On the other hand, it was observed that backfat depth of sows in both rooms decreased as each trial progressed; this cannot be attributed to the modifications done in the ventilation system in the treatment room as both rooms showed the same trend.

Room cleanliness

Sow dirtiness was assessed weekly during each trial by following a 0 to 4 dirtiness score: 0 – completely clean; 1 – mostly clean; 2 – some dirt; 3 – dirty; and 4 – very dirty. Over four trials, it was observed that sows in the treatment room were relatively 'cleaner' than sows in the control room. Sows in the treatment room had an average dirtiness score of 2 which indicates that only their hooves and 20 % of their legs and body were soiled. On the other hand, sows in the control room had an average dirtiness score of 3 which implies that their hooves and 50 % of their legs and body were soiled. Similar result was observed after assessment of pen dirtiness. Consistently, the treatment room had 25 to 50 % of its floor covered with manure while the control room had about 50 to 75 % of its floor covered with faeces and urine. Dirtiness of sows as well as pens is a good measure of an effective ventilation system, which in this case, implies that the horizontal air flow ventilation system in the treatment room was relatively more effective than that in the control room.

CONCLUSIONS

Results from the computer simulation work have confirmed the need to re-design the ventilation system of a newly-converted group sow housing facility. Among all the design configurations tested, horizontal flow ventilation system was the most effective in removing heat from the animal occupied zone (AOZ) in the room during both summer and winter seasons.

In-barn evaluation of the selected ventilation system design showed about 21% reduction in natural gas consumption during heating season and 14% reduction in electricity consumption in the room with the horizontal flow ventilation system relative to the control room with the unmodified ventilation system.

The new ventilation system design for group sow housing has provided better air quality and cleaner floors than the unmodified ventilation design. Also, the room with the new ventilation design had relatively cleaner floors than the room with the unmodified ventilation design.

Animal performance and productivity were not adversely nor beneficially impacted by having a horizontal flow ventilation system in a gestation room.

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