The Canadian Society for Bioengineering
The Canadian society for engineering in agricultural, food, environmental, and biological systems.

La Société Canadienne de Génie Agroalimentaire et de Bioingénierie
La société canadienne de génie agroalimentaire, de la bioingénierie et de l'environnement

CSBE | SCGAB

Paper No. CSBE16-054

Computer Simulation and In-barn Evaluation of Modified Ventilation System in Sow Gestation Barn Converted to Group Housing

Bernardo Predicala, Ph.D.

Prairie Swine Centre Inc., Box 21057, 2105 - 8th St., Saskatoon, Saskatchewan, Canada S7H 5N9
Tel: 306 667 7444, Email: bernardo.predicala@usask.ca

Alvin Alvarado, M.Sc.

Prairie Swine Centre Inc., Box 21057, 2105 - 8th St., Saskatoon, Saskatchewan, Canada S7H 5N9

Written for presentation at the
CSBE/SCGAB 2016 Annual Conference
Halifax World Trade and Convention Centre
3-6 July 2016

ABSTRACT Many of the existing sow farms in Canada face the challenge of remodeling current barns or designing new facilities to meet regulatory and societal demands to convert from stalls to group housing system. In the barn conversion process, most pig farmers focus mainly on remodeling the penning and floor layout to transform the barn to group housing, while the ventilation system is frequently neglected or overlooked. In this study, various configurations of the ventilation system of a newly-converted group sow housing facility were evaluated to determine the necessary changes to the ventilation system that must be done when converting sow barns from stalls to group housing system. Computer simulation was utilized to develop and evaluate different ventilation system design configurations, followed by actual in-barn evaluation of the selected ventilation design configuration to assess its impact on actual energy costs, indoor air quality, and sow productivity. 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 this ventilation system design showed about 21% reduction in natural gas consumption during heating season and 14% reduction in electricity consumption relative to a similar room with unmodified ventilation system. Analysis of incremental costs from the in-barn implementation showed that energy savings from this modified ventilation system can offset the capital and operating costs for installing the system, with estimated payback period of about 2.2 years.

Keywords: barn conversion, computational fluid dynamics, group housing, swine, ventilation

INTRODUCTION There are about 3,500 pig farms in Canada with sows and gilts on farm (Statistics Canada Census of Agriculture). In these farms, pregnant sows are traditionally kept in stall systems during their gestation period, but in response to increasing public demand for improved animal welfare in pig production, the recent revision to the Canadian Code of Practice for the Care and Handling of Pigs has mandated that sows should be reared in the more welfare-friendly group housing system (NFACC, 2013). As the pig industry shifts from conventional stall system to group housing for sows, many producers have already made efforts to convert their barns to group systems. However, barn conversion is a complicated process and requires significant investment, which make it imperative that it should be done right. Most of the previous work on this area has made significant progress on identifying the best options for re-configuring barn floor lay-outs and pen configurations to comply with the new space requirements per animal. In the barn conversion process, most pig farmers focus mainly on remodeling the penning and floor layout to transform the barn to group housing, while the ventilation system is frequently neglected or overlooked (Harmon, 2013).

Ventilation affects many aspects of the animal environment as well as barn operating costs (i.e., energy cost). Retaining the existing ventilation system as-is in a converted sow barn will lead to over-ventilation during winter (because the existing minimum ventilation fans are designed for higher animal density), thereby using extra fan energy and heating fuel, and most likely cause chilling of the animals and adversely affecting their performance. According to Harmon et al. (2010), if ventilation is continued at the pre-remodeling level (prior to group housing), the building would be over-ventilated by one third (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%. As such, there is a need to re-visit the existing ventilation system in order to ensure that the investment on barn conversion leads to successful and sustainable operation of the remodeled facility.

OBJECTIVES The overall goal of this project was to re-design the ventilation system of a gestation barn converted from traditional stalls to a group sow housing system, to reduce energy cost, and improve overall air quality and sow performance. The specific objectives were to:

1. develop and evaluate different ventilation system design configurations using computer simulation;

2. apply selected ventilation design configuration in an actual gestation barn with group-housed sows and assess its impact on actual energy costs, indoor air quality, and sow productivity, and;

3. conduct feasibility analysis of the newly developed ventilation design.

METHODOLOGY Based on the above objectives, this project was carried out in two phases.

Phase 1 - 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. Summary of the different design configurations investigated is shown in Table 1.

Table 1. Ventilation system design configurations investigated in the simulation work.

Housing type	Ventilation rate, m^3/s Summer	Winter	Flow direction	Exhaust fan location	Inlet location	Code
Stall*	3.78	0.32	Downward	Wall	Ceiling	SDWC
Group**	3.78	0.32	Downward	Wall	Ceiling	GrDWC
Group***	2.94	0.25	Downward	Wall	Ceiling	GDWC
				Wall	Ceiling + recirculation duct	GDWC-RD
				Sidewall	Ceiling	GDSC
				Pit	Ceiling	GDPC
			Upward	Wall	Sidewall - close to floor	GUWSF
				Chimney (ceiling)	Sidewall - close to floor	GUCSF
				Chimney	Sidewall - close to ceiling	GUCSC
				Chimney	Ceiling	GUCC
			Horizontal	Wall	Wall - longitudinal	GTWW
				Right sidewall	Left sidewall	GTSS

*Pre-conversion barn with 54 sows in stall system and using the current ventilation system
**Converted barn with the new group housing lay-out and new number of sows (42) but using the existing (unmodified) ventilation system
***Converted barn with ventilation system modified using various configuration options.

Each design configuration was assessed based on ventilation effectiveness which is an indicator for uniform mixing and elimination of dead zones and unwanted drafts (van Wagenberg and Smolders, 2002; Breum et al., 1990). Ventilation effectiveness was evaluated based on the effectiveness of removal of heat (HRE) from the animal occupied zone (AOZ) calculated as follows (van Wagenberg and Smolders, 2002):

$$HRE = (T_{outlet} - T_{inlet}) / (T_p - T_{inlet}) \qquad (1)$$

where HRE is the dimensionless heat removal effectiveness at point p; T_{inlet} is temperature of the inlet air, °C; T_{outlet} is temperature of the outlet air, °C; T_p is temperature at point *p* in the room, °C. The value of HRE can be above or below 1. According to van Wagenberg and Smolders (2002), HRE values greater than 1 indicate that fresh air enters the AOZ first and then passes the contaminant sources on its way to the outlet, which indicates effective air displacement in the AOZ. HRE values below 1 indicate that the temperature level in the AOZ exceeds the temperature in the outlet air. Low values of HRE translate to high contaminant levels at the AOZ that are not being efficiently removed by the ventilation system.

The 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.

Phase II - Actual barn implementation of the most effective ventilation system design

The goal of this phase of the study was to implement the most effective ventilation system design based from computer simulation results and to assess its impact on actual energy costs, indoor air quality, and sow welfare and productivity under conditions that are representative of actual commercial sow barns.

Description of facilities and experimental set-up

Two production rooms of equal size at the PSC barn facility were configured for group sow housing system. One room designated as the Treatment room was modified following the most effective ventilation design configuration identified from the simulation work while the other room with ventilation system configured similar to a pre-converted sow barn with stall system served as Control room. Figure 1 shows the rooms re-configured for group sow housing system. 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). 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). Each room has inside dimension of 23.1 ft (W) x 65 ft (L). Two electronic sow feeders (Gestal 3G, Jyga, Quebec) and four nipple drinkers were installed in each 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.

Experimental procedure

Equal number of sows was housed in the two rooms per trial with an average of about 42 sows per room per trial. A total of 4 replicate trials were carried out in the two rooms, with each trial lasting for 4 weeks. When gilts were included as part of the group, they were moved in to the rooms 1 week ahead of the rest of the sows in the group for training on the use of the sow feeders.

Data collection and analysis

Air temperature (at sow level) and relative humidity at the different spatial locations in both rooms were monitored using thermocouples and RH sensors, respectively. These parameters were measured continuously throughout the trial using OMEGA USB data loggers (Spectris Canada Inc., Laval, QC). Carbon dioxide levels at the different spatial locations in the room were monitored once a week using a direct-reading CO_2 monitor (CO2 Meter, Inc., Ormond Beach, FL, USA). Air velocity at the inlets and at different locations in each room was monitored every week using a direct-reading anemometer (TSI Alnor, TSI Inc., Shoreview, MN). Room static pressure was measured by a pressure transducer (Setra 265, Setra, Boxborough, MA) installed in each room. Ventilation rate was measured by installing an air flow sensor (D6F-W10A1, Omron Electronics Inc., Canada) on each fan in both rooms. Electric current and voltage sensors were installed in both rooms to measure continuously the electrical energy consumption of the ventilation fans, heaters, and lights throughout each trial. Natural gas meter was also installed to monitor the heater gas consumption of the supplemental (forced-convection) heater in each room. Data were logged continuously using a CR1000 data logger (Campbell Scientific, Edmonton, AB).

Average daily gain was based on the average growth rates determined by taking the difference in sow's weight at the start and end of the 4-week trial. Back fat depth of sows was determined every weighing day using a real-time ultrasound scanner (Pie Scanner 200 SLC, Pie Medical, The Netherlands). Additionally, sow body condition was assessed according to a 1 to 5 condition score.

The data collected from this study, together with the information on costs incurred during actual implementation of the new ventilation system design, were used in carrying out an economic analysis to calculate financial indicators (e.g., payback period) for the investment on modifying the ventilation system for the converted barn.

RESULTS AND DISCUSSION

Phase 1 - Assessment of ventilation system designs using computer simulation

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. Inlet temperature and the corresponding moisture concentration were based from the average minimum winter and maximum summer temperatures from climatological records for Saskatchewan, Canada. Ventilation rates for the stall and group housing systems were based from 0.07 m^3/s-sow (150 cfm/sow) for summer and 0.006 m^3/s-sow (12 cfm/sow) for winter recommended by the Midwest Plan Service (MWPS, 1990). The total ventilation rate of the two housing systems were based on the number of sows housed in the room; 54 sows for the stall system and 42 sows for the newly-converted group system. The sows were assumed to be 190 kg on average, which impacted the total heat and moisture production of all the sows in the room. In addition, the heat transfer coefficient of the walls and ceilings were based on the thermal resistance (R-value) of the building components and insulation material.

Ventilation effectiveness

Table 2 shows the heat removal effectiveness (HRE) of the different ventilation system configurations during periods with high and low ventilation. The values represented nine different points in the room with each point located at the animal occupied zone (AOZ) approximately 1 m above the pen floor. According to van Wagenberg and Smolders (2002), the average HRE values in the AOZ provide a better indication of the effectiveness of air displacement. In general, HRE values at high ventilation rates were not influenced by the general air flow direction.

In general, with the group housing layout and new ventilation design, HRE value 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 (GTWW). GTWW 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 AOZ had HRE values greater than 1 (lowest HRE was 1.08) which indicate that the air was homogeneously mixed. Effective removal of heat from the AOZ (HRE > 1) is desirable at high ventilation rates during summer season when ventilation is mainly for temperature control at the AOZ (van Wagenberg and Smolders, 2002).

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, GTWW still had HRE values greater than 1 in all 9 monitoring points. On average, GTWW had an HRE value of 1.11 ± 0.12, which was the highest among all the designs tested for winter. Furthermore, the room with the stall system (SDWC) and the converted room with unmodified ventilation system (GrDWC) had average HRE values less than 1, indicating 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.

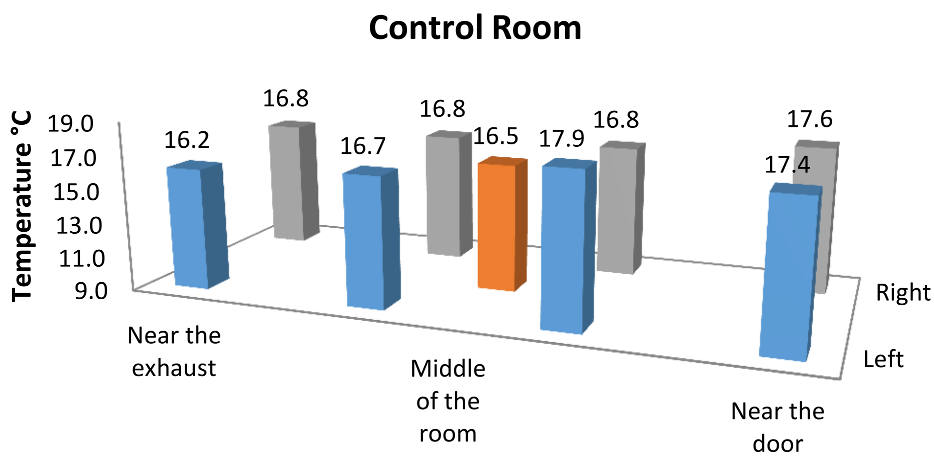
Table 2. Mean (±SD) values of heat removal effectiveness (HRE) of the different ventilation system design configurations simulated under summer and winter conditions, n=9.

Design code	Flow direction	Heat Removal Effectiveness	
		Summer	Winter
SDWC	Downward	1.18 (0.49)	0.85 (0.10)
GrDWC	Downward	1.17 (0.36)	0.83 (0.12)
GDWC	Downward	1.20 (0.22)	0.87 (0.10)
GDWC-RD	Downward	1.03 (0.23)	0.93 (0.09)
GDSC	Downward	1.18 (0.30)	1.06 (0.12)
GDPC	Downward	0.95 (0.07)	0.95 (0.04)
GUWSF	Upward	0.91 (0.24)	0.94 (0.06)
GUCSF	Upward	1.08 (0.32)	1.10 (0.14)
GUCSC	Upward	0.90 (0.23)	1.11 (0.07)
GUCC	Upward	1.19 (0.31)	1.10 (0.29)
GTWW	Horizontal	1.32 (0.23)	1.11 (0.12)
GTSS	Horizontal	1.01 (0.43)	1.06 (0.10)

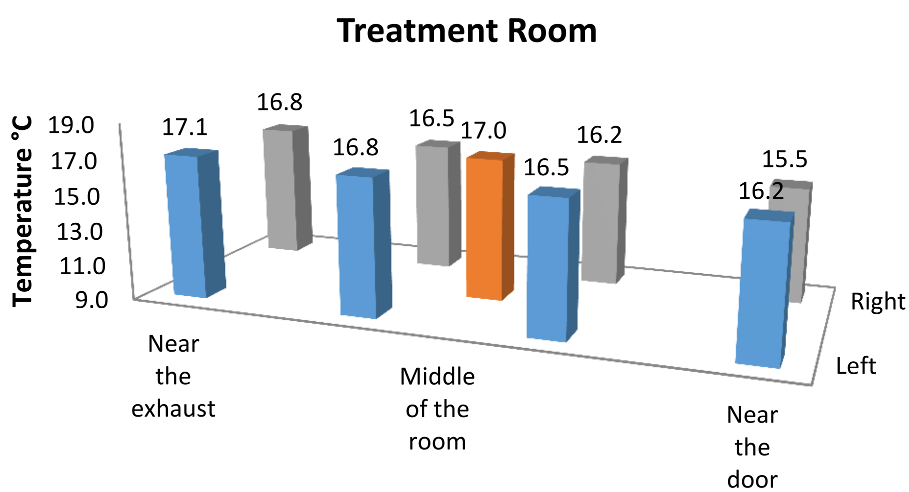
Phase 2 - Actual barn implementation of the most effective ventilation system design

Modified (Treatment) vs. Unmodified (Control) ventilation system

Figure 2 shows the average air temperature readings at 9 different locations in each room over four trials. Average air temperature in the control and treatment rooms were uniformly distributed ranging from 16.2 to 17.9 °C and 15.5 to 17.1 °C, respectively (Figure 2A and 2B). Set-point temperature in these rooms was set at 16.5 °C which is the typical set-point temperature in actual gestation barns. In the treatment room, the temperature near the door was relatively lower than the other locations because these areas were the closest to the air inlets. Significant difference ($p<0.05$) was observed at the exhaust with the average air temperature of 14.9 °C and 18.0 °C for the control and treatment rooms, respectively. This implies that the ventilation system in the treatment room is effective in removing heat from the room as compared to the control room.



A



B

Figure 2. Average air temperature measured at the animal-occupied zones in the Control room (A) and the Treatment room (B) over 4 trials.

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 CO_2 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 is efficiently removed from the treatment room as compared to the control room, which is consistent with the HRE values calculated in both rooms.

In terms of relative humidity, no considerable difference was observed between the two rooms. The treatment room had an average RH of 75.8% at the inlet and 57.5% at the exhaust. The control room on the other hand, had an average RH of 75.3% at the inlet and 58.3% at the exhaust. Furthermore, average air velocity in the control room was almost the same as that in the treatment room. The control room had an average air velocity ranging from 0.06 to 0.12 m/s while the treatment room had 0.07 to 0.11 m/s.

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.

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.

The natural gas consumed for heating and the electricity consumed by the fans, room heater, and lights comprised the energy consumption of the room (Table 3). During winter, the treatment room with the horizontal flow ventilation system consumed an average of 608.7 m^3 of natural gas over four weeks for heating; this was about 21% higher than the control room which had an average of 767.2 m^3 natural gas consumed. Similarly, the average electricity consumption in the treatment room over four trials was about 250.33 kWh while the control room used about 293.55 kWh of electricity to heat and ventilate the room during this period. The considerable difference in the total energy consumption (natural gas and electricity) between the two rooms during the winter season was mainly due to the frequency of heater operation; heater in the control room run more frequently than that in the treatment room. On the other hand, during the summer season, the difference in electricity consumption between the two rooms can be attributed to the operation of the fans which was dependent on the temperature maintained in the rooms during the trial. It can be observed that the temperature in the treatment room was relatively lower (but still within the range of recommended temperature) than the control room; this difference translated to relatively lower energy consumption in the treatment room than in the control room.

Table 3. Energy consumption for heating and ventilation in the control and treatment rooms over four trials.

Trial*		Natural gas consumption, m^3		Electrical consumption, kWh	
		Control	Treatment	Control	Treatment
Summer	1	-	-	378.19	311.75
	2	-	-	243.70	200.52
Winter	3	718.4	206.7	268.93	211.79
	4	816.1	1,010.8	283.40	277.27
Average		767.2	608.7	293.55	250.33

*Each trial lasted for four weeks

A cost analysis of the installation of the horizontal flow ventilation system in a gestation room was carried out after completion of the actual room experiments. Capital and installation expenses were the incremental cost of installing the new ventilation system which included the cost of required materials (e.g., plywood, insulation material, pulleys, hooks, etc.), and labour for installation. It was assumed that the inlets from the old ventilation system were used in the new design. Thus, the room with the new ventilation system design incurred an incremental cost for capital and installation of about $1,150.00 which was equivalent to $0.27 per sow per year. For the heating cycle, the natural gas consumption of the treatment room with the horizontal flow ventilation system was about 3,044 m^3 per year. Using the prevailing cost of natural gas in Saskatchewan, this consumption translated to about $1.35 per sow per year, which was $0.35 per sow per year less than the natural gas consumption of the control room with the unmodified ventilation system ($1.70 per sow per year). Additional savings resulting from adopting the new ventilation system was from electricity consumption. On a yearly basis, the total electricity consumed in the treatment room was about 3,254 kWh, which was about 562 kWh lower than the control room (3,816 kWh). This difference translated to a savings of about $0.20 per sow per year.

Summing up all the costs incurred (capital and installation, energy costs for heating and ventilation) after each of the ventilation system designs was installed in a gestation room, the total cost associated with the new ventilation system design was about $2.83 per sow per year; about $0.28 per sow per year savings relative to the control room with the unmodified ventilation system ($3.11 per sow per year). In a 2400-sow operation, for instance, the potential returns for the gestation barn from adopting the horizontal flow ventilation system is about $672.00 per year which translates to a payback period of about 2.2 years. It is important to note that in this analysis, savings from adopting the new ventilation system are acquired from energy consumption alone.

CONCLUSIONS Based on the findings of this study, the following conclusions can be made:

1. 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.

2. 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.
3. 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.
4. Animal performance and productivity were not adversely nor beneficially impacted by having a horizontal flow ventilation system in a gestation room.
5. Analysis of the costs associated with actual in-barn implementation of the two ventilation designs showed that compared to the room with the unmodified ventilation system, the adoption of the new ventilation system design in a gestation room could lead to as much as 18% reduction in total heating and electricity costs, which can readily offset the capital and operating costs for installing this system.

Acknowledgements. Financial support for this project has been provided by Agriculture Council of Saskatchewan Inc. through the Advancing Canadian Agriculture and Agri-Food Saskatchewan (ACAAFS) program, and the Saskatchewan Agriculture Development Fund. Strategic funding provided to the Prairie Swine Centre by the Saskatchewan Pork Development Board, Manitoba Pork Council, Alberta Pork, Ontario Pork, and the Saskatchewan Ministry of Agriculture is also acknowledged. Technical assistance provided by Richard Baah, Sam Gelowitz, Karu Bandaralage, Kelly Sauder, and other PSC staff is greatly appreciated.

REFERENCES

Breum, N.O., H. Takai and H.B. Rom, 1990. Upward vs. downward ventilation air flow in a swine house. Transactions of the ASAE 33(5): 1693-1699.

Harmon J. 2013. Group housing systems: New and conversion construction. National Pork Board, Des Moines, IA.

Harmon, J, M. Hanna and D. Petersen. 2010. Sizing minimum ventilation to save heating energy in swine housing. Iowa State University. PM2089J. Available at: https://store.extension.iastate.edu/Product/Sizing-Minimum-Ventilation-to-Save-Heating-Energy-in-Swine-Housing-Farm-Energy

MWPS, 1990. Mechanical ventilating systems for livestock housing. Midwest Plan Service, Ames, IA.

NFACC. 2014. Code of Practice for the Care and Handling of Pigs. Canada: National Farm Animal Care Council. https://www.nfacc.ca/pdfs/codes/pig_code_of_practice.pdf. Accessed May 15, 2015.

Van Wagenberg, A. V., and M. A. H. H. Smolders. 2002. Contaminant and heat removal effectiveness of three ventilation systems in nursery rooms for pigs. Transactions of the ASAE 45(6): 1985-1992.