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Field performance evaluation of a ventilation system: a swine case study

Jay D. Harmon

Iowa State University, jharmon@iastate.edu

Michael C. Brumm

University of Nebraska-Lincoln, mbrumm@hickorytech.net

Larry D. Jacobson

University of Minnesota, St. Paul, Minnesota, jacob007@umn.edu

Stephen H. Pohl

South Dakota State University

David R. Stender

Iowa State University, dstender@iastate.edu

See next page for additional authors

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Authors

Jay D. Harmon, Michael C. Brumm, Larry D. Jacobson, Stephen H. Pohl, David R. Stender, and Richard R. Stowell

FIELD PERFORMANCE EVALUATION OF A VENTILATION SYSTEM: A SWINE CASE STUDY

J. D. Harmon, M. C. Brumm, L. D. Jacobson, S. H. Pohl, D. R. Stender, R. R. Stowell

ABSTRACT. *Swine finishing facility ventilation has become relatively complex and is often mismanaged as a system. One of the few ways to truly understand these systems is to spend time systematically going through the many components of the building and how they work as a system. To learn to help producers better, a team of university Extension specialists that included agricultural engineers and animal scientists spent an extended period carefully documenting conditions in a deep-pit swine finishing building with two 1,000-head rooms. Exhaust fans connected to the manure pit and wall fans were operated at various stages as a negative-pressure ventilation system. A computerized controller activated exhaust fans, a ventilation curtain actuator, heaters, stir fans, and a spray cooling system. Gravity-controlled baffled ceiling inlets were evenly spaced in the building to provide good air distribution during cold and mild weather conditions. Following the review of current conditions and operating parameters, performance deficiencies were identified and recommendations were given regarding controller settings, inlet settings, and the transition to natural ventilation. Specific recommendations included changing minimum ventilation speed settings of fans based on animal size, removing inlet stops during warmer weather to avoid premature transition to natural ventilation, a change in how fans were staged, a change in setpoint, and the specific temperature at which the cooling system was engaged.*

Keywords. *Ventilation fans, Controlled environment, On-farm assessments, Ventilation system, Swine.*

Over the last 40 years, swine buildings have progressed from simple concrete floors with minimal shelter from inclement weather to sophisticated buildings offering a premium environment to optimize growth and feed efficiency. Ventilation control systems are a critical element of modern animal production systems, yet they are often misunderstood and mismanaged. For example, mismanagement can result in excessive energy usage for heating due to improper heater or minimum ventilation settings, an uncomfortable environment which reduces swine productivity, or animal heat stress. As part of a four-state educational program involving Iowa, Minnesota, Nebraska, and South Dakota (Pohl et al., 2004), information was assimilated by a team of

educators in order to develop an appropriate extension program to address pork producer needs related to environmental control. Educational needs were identified through discussions with producers and then further refined using feedback provided by ventilation workshop participants. Swine producer educational needs focused on the components of an environmental control system, including fans, inlets, heaters, controllers, and ventilation curtains, as well as the way the components work together to function as a system. This article documents a case study in which the educational team evaluated a swine finisher ventilation system and used the results to develop future educational programs.

The objectives of this article are to: 1) illustrate a procedure for evaluating swine facility ventilation system, including ventilation capacity, inlet management and controller settings, 2) discuss typical problems encountered in these buildings, and 3) identify lessons helpful in educating swine producers.

PROBLEM DESCRIPTION

BUILDING USAGE AND LAYOUT

The production site selected for evaluation was located near the northwest corner of Iowa. The single building held 2,000 head of finishing pigs; 1,000 in each of two identical rooms. Swine finishing buildings generally are filled with pigs that have been raised from weaning to approximately 27 kg (60 lb) in a swine nursery facility before being moved to a finishing facility like this one. Pigs are marketed from the finishing building when they reach a range of 118 to 127 kg (260 to 280 lb). It is important to make the distinction between a “finishing” facility and another type of building called a “wean-to-finish” facility. Both types of facilities

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The authors are **Jay D. Harmon, ASABE Fellow**, Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, Iowa; **Michael C. Brumm, ASABE Member**, Professor Emeritus, University of Nebraska, Lincoln, Nebraska & Brumm Swine Consultancy, Inc., Mankato, Minnesota; **Larry D. Jacobson, ASABE Fellow**, Professor, Department of Bioproducts & Biosystems Engineering, University of Minnesota, St. Paul, Minnesota; **Stephen H. Pohl, ASABE Member**, Professor, Department of Agricultural & Biosystems Engineering, South Dakota State University, Brookings, South Dakota; **David R. Stender**, Extension Field Specialist, University Extension, Iowa State University, Ames, Iowa; and **Richard R. Stowell, ASABE Member**, Associate Professor, Department of Biological Systems Engineering, University of Nebraska, Lincoln, Nebraska. **Corresponding author:** Jay D. Harmon, Department of Agricultural and Biosystems Engineering, Iowa State University, 200 Davidson Hall, Ames, IA 50011; phone: 515-294-0554; e-mail: jharmon@iastate.edu.

grow pigs to market size, but in a wean-to-finish building, pigs are weaned directly into the building when they weigh approximately 5 to 6 kg (12 lb); the smaller pigs have lower ventilation requirements and generally require zone heating.

The overall building was approximately 12.5 m (41 ft) wide \times 124 m (408 ft) long and was oriented with the roof ridge running east and west. Each room was 12.5 \times 61 m (41 \times 200 ft), with a workroom between the animal rooms. The building had a 2.4-m (8-ft) deep manure storage pit beneath a fully slotted concrete floor and was divided to create independent air spaces in the two rooms.

The building was constructed with a concrete foundation and manure pit with stem walls extending approximately 0.6 m (2 ft) above grade. The building shell was constructed using a lightweight wood frame with steel siding and roofing. This construction technique is typical for swine facilities in Iowa. Figure 1 shows the building exterior. The ceiling was constructed of steel on the lower chord of the roof truss system. Endwalls and the ceiling were appropriately insulated. A center walkway in each room allowed access to 20 pens (3 \times 5.7 m) on either side of the aisle.

VENTILATION SYSTEM

The goal of any swine ventilation system is to provide a suitable environment for pigs to grow efficiently while conserving heating energy in winter and minimizing heat stress in summer. This system must adjust to changing weather conditions and increasing heat and moisture loads associated with growing pigs. MWPS (2001) stated that the environmental goals for pigs should be to maintain a relative humidity below 60%, carbon dioxide below 2500 ppm, ammonia below 10 ppm, and hydrogen sulfide below 1 ppm. However, animal welfare assessment programs such as the National Pork Board's Pork Quality Assurance Plus program (PQA Plus) require that a time weighted average value for ammonia should be below 25 ppm (NPB, 2010). This is generally viewed as a more achievable and acceptable goal

for ammonia, especially in deep-pit swine finishing. Minimum ventilation is provided to the building to maintain relative humidity and gases below the prescribed levels. Over-ventilating during cold weather wastes heating energy and adds unnecessary production expense. The ventilation system responds to increasing temperature in the animal room by increasing the ventilation rate. Supplemental cooling is utilized once the room temperature exceeds a setpoint temperature as set by the operator.

The ventilation system was designed to function as a negative-pressure mechanical ventilation system during colder weather and uses natural wind-driven ventilation in the summer. The mechanical portion of the system used fans to exhaust air, thereby reducing the static pressure in the animal room to create a static pressure difference between the ambient environment and the animal room. This pressure difference drew air in through ceiling inlets which were used to distribute the air. Operational static pressure difference between the ambient environment and the animal zone is normally 15 to 20 Pa (0.06 to 0.08 in. H₂O) but may operate near 10 Pa (0.04 in. H₂O) in winter and 30 Pa (0.12 in. H₂O) in systems that use mechanical ventilation during summer (Wilson et al., 1983). The natural ventilation portion of the system used sidewall curtains that open during warm weather and use wind to drive air exchange.

The mechanical ventilation system used ten exhaust fans – five per room. Each room had four fans mounted on the manure pit access ports [approximately 1.2 \times 1.2 m (4 \times 4 ft)], which were evenly spaced along the south side of the building. An additional fan was located on each end wall of the building. Figure 2 shows the approximate location of ventilation components. Fans were equipped with discharge cones (GSI Model APP-24F; Automated Production Systems, Assumption, Ill.) and were 0.61 m (24 in.) in diameter. The rated capacity (BESS, 2008) of these fans was 3.31 m³/s (7,010 cfm) @ 12.5 Pa (0.05 in. H₂O). The fans were configured in stages as shown in table 1.



Figure 1. Exterior view of the 2,000-head swine finishing facility.

Table 1. Fan stages based on rated fan capacity at 12.5 Pa (0.05 in. of H₂O).

Ventilation Stage	Number of Fans in Stage	Speed Variable?	Max. Stage Airflow	Cumulative Airflow	Cumulative Airflow/pig
1	2	Yes	6.62 m ³ /s (14,020 cfm)	6.62 m ³ /s (14,020 cfm)	23.8 m ³ /h-pig (14.0 cfm/pig)
2	2	Yes	6.62 m ³ /s (14,020 cfm)	13.2 m ³ /s (28,040 cfm)	47.5 m ³ /h-pig (28.1 cfm/pig)
3	1	No	3.31 m ³ /s (7,010 cfm)	16.5 m ³ /s (35,050 cfm)	59.6 m ³ /h-pig (35.6 cfm/pig)

Sidewall ventilation curtains were used to take advantage of predominate warm-weather winds that provided natural ventilation across the building. The sidewalls (north and south) of each room had 1.5-m (5-ft) openings that were covered with non-permeable ventilation curtains and attached at the tops of the stem walls. These curtains were operated using a winch and cable system to regulate the opening width and open from the top first (near the ceiling). The two curtains on each room shared one winch system and operated together while the rooms operated independently. The curtain began opening once all ventilation fans were running and the curtain “on temperature” was reached. Control of the curtain was accomplished by using an on/off time strategy. The winch system moved the curtain up or down at the rate of 30 cm (12 in.) per minute. After the curtain moved the programmed time, there was an off time programmed. If the room temperature was still above the curtain “on temperature” at the end of the off time, the winch would lower the curtain by operating for the programmed “on” time and wait for another response. If the room temperature dropped below the controller setting, the curtain would close in a similar manner. A whisker switch within the curtain winch would deactivate fans once the curtain dropped approximately 30.5 cm (12 in.).

Twelve gravity-controlled box inlets were evenly spaced in the ceiling over the center walkway along the length of each room (fig. 2). These inlets used a counter-weighted baffle that responded to static pressure difference and drew air from the attic during mechanical ventilation operation. Each box inlet directed airflow in two directions, toward both sidewalls. The openings on the 12 inlets were 61 cm (24 in.) long on each side. According to MWPS (1990a), during normal operation the average inlet jet velocity should be between 3.0 to 5.1 m/s (600 and 1000 fpm). The inlet capacity was rated by the manufacturer (Automated Production Systems, Assumption, Ill.) at 1.47 m³/s @ 25 Pa (3,120 cfm @ 0.10 in. H₂O) when the counterweight was approximately 7.6 cm (3 in.) from the end. This results in a total rated inlet capacity of 17.7 m³/s (37,440 cfm) or 63.6 m³/h-pig (37.3 cfm/pig) in each room.

During mechanical ventilation outdoor air entered the attic via eave openings along the south wall. The eave opening provided at least 9.3 m² (100 ft²) for air intake and was determined to be sufficient using the criteria given by Albright (1990) which states that the upstream opening should be 2.5 times the area of the inlet. Providing this amount minimizes pressure loss through the eave opening. A similar rule-of-thumb recommendation is to design the calculated airspeed through the opening below 2 m/s (400 fpm). The maximum rated air flow through the attic was 16.5 m³/s (35,050 cfm) according to table 1. Dividing the maximum rate by the rule of thumb speed yields a required area of 8.25 m² (88 ft²), which is less than what is provided; therefore the system has an adequate eave opening to the attic.

Each room had two liquefied petroleum gas fired space heaters, with a nominal capacity of 72 kW (250,000 Btu/h) each. Heaters were located near the curtain sidewalls blowing in opposite directions. They did not unduly influence the temperature sensors. For interior air movement to assist with pig convective cooling, eight basket 61-cm (24-in.) stir fans were located along the south edge of each room pointed slightly downward and toward the north. For

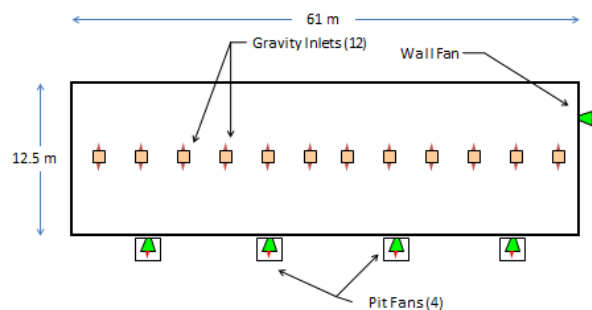


Figure 2. Ventilation layout for one room for the deep-pit manure swine finishing building (not to scale). Pits fans are located on the south side of the building.

further cooling, water sprinkling nozzles were located over each pen and cycled on and off to allow evaporation between wetting cycles.

EVALUATION

Several facets of the ventilation system were evaluated during this field study. These include minimum ventilation rate, inlet settings, staging of fans, and temperature settings. Hot weather operation was not observed, but the system was evaluated for year-around operation using comparisons of equipment capabilities to standard Midwestern swine production practices.

CONDITIONS DURING EVALUATION

The facility was evaluated on a December day with an outdoor air temperature of 1°C (34°F). Pigs in the finishing facility weighed approximately 91 kg (200 lb) at the time of analysis. They were placed in the building with an initial weight of approximately 27 kg (60 lb) and normally marketed at 124 kg (273 lb). Normal feed efficiency in the building ranged from 2.65 to 2.95 kg feed/kg gain with average daily gains of 0.72 to 0.84 kg/day (1.60 to 1.85 lb/day).

Controller settings for the heating, cooling, and ventilation stages for the day of the farm visit are shown in table 2. At minimum ventilation, the controller was set with the intent that the two stage 1 fans would each deliver 60% of rated capacity or 2.0 m³/s (4,200 cfm), however the 60% setting on the controller does not necessarily imply that fans are operating at 60% airflow capacity. As the room temperature increased above the setpoint of 19.5°C (67°F), the controller linearly increased the percentage within the controller to the stage 1 fans until they were operating at full speed when the room temperature reached 20°C (68°F). This temperature difference is often referred to as the “bandwidth” with many controllers. Fan stage 2 came on when room temperature reached 20.5°C (69°F) or 0.5°C (1°F) above the point at which stage 1 reached full-speed. Stage 2 is also capable of variable-speed control, but was being utilized as a single-speed fan stage by setting the minimum speed to 100%. The temperature difference between fan stages is often referred to as the “differential.” Stage 3 had the same differential as stage 2, activating 0.5°C (1°F) above the point at which stage 2 reached maximum speed. As the room

Table 2. Controller settings at the time of the assessment.

Stage	ON Temperature	Other Stage Information
Heating	18°C (64.5°F)	OFF temperature: 18.6°C (65.5°F)
Setpoint	19.4°C (67°F)	
Fan stage 1, variable-speed	Continuous Capacity increased above 19.4°C (67°F) up to 20°C (68°F)	60% minimum setting 100% at or above 20°C (68°F) Bandwidth of 0.6°C (1°F) Motor curve 4 (sets supply voltage curve to fans)
Fan stage 2, variable-speed	20.6°C (69°F)	0.6°C (1°F) differential above Stage 1 100% minimum speed setting (acts as single speed with this setting) Bandwidth of 0.6°C (1°F) Motor curve 4
Fan stage 3, single-speed	21.7°C (71°F)	0.6°C (1°F) differential above Stage 2
Curtains	22.5°C (72.5°F)	0.8°C (1.5°F) differential above Stage 3 Move for 15 s / wait for 120 s (at 30 cm/min or 12 in./min)
Cooling: Basket stir fans	28°C (83°F)	
Cooling: water sprinkling	31.5°C (89°F)	Cycled

temperature continued to increase, the curtains began to open to provide additional ventilation through natural means, and cooling systems were staged on at progressively higher temperatures. Once the curtain system was activated, the curtains moved for 15 s, which was a travel distance of 7.5 cm (3 in.), and then remained at that location for 120 s. After this wait cycle the curtain would then open farther if the temperature was above the curtain activation temperature or it would begin to close if the temperature had fallen below this temperature.

MEASUREMENT EQUIPMENT

Equipment to measure building performance parameters was selected that is relatively common to professionals working with swine ventilation. Parameters measured included temperature, relative humidity, air speed, static pressure, gas concentrations (carbon dioxide, ammonia, and hydrogen sulfide), and voltage.

A Kestrel® 3000 pocket wind meter (Nielsen Kellerman, Boothwyn, Pa.) was used for measurement of temperature, relative humidity, and air speed. Stated accuracy by Nielson Kellerman (2010) is 1°C (1.8°F) for temperature and 3.0% for relative humidity with resolution of 0.1 for both. For air speed the accuracy was stated as the larger of 3% of the reading or the least significant digit. Resolution for air speed was 0.1 m/s (1 fpm).

Static pressure was measured using a Magnehelic® differential pressure gage (model 2000-00, Dwyer Instruments, Inc., Michigan City, Ind.). This model, as stated by Dwyer Instruments (2010), has a range of 0 to 62 Pa (0 to 0.25 in. H₂O) with an accuracy of $\pm 2\%$ full scale and resolution of 1.2 Pa (0.005 in. H₂O).

Gases were measured using a Sensidyne aspirating detector tube pump (100 mL, Sensidyne, LP, Clearwater, Fla.) and gas detector tubes. For carbon dioxide, the Sensidyne 126SF tubes having a range of 100 to 4000 ppm were used. For ammonia, the Sensidyne 105SE tubes having a range of 1 to 200 ppm were used. Sensidyne 120SE tubes with a range of 0.5 to 40 ppm were used for hydrogen sulfide.

Voltage associated with the variable-speed fans was measured with a true-RMS multimeter (Fluke Corporation, Everett, Wash.). Variable-speed controllers “chop” the voltage and provide motors with non-sinusoidal currents. The current occurs in short pulses rather than smooth sine

waves. An average responding multimeter is appropriate for linear loads such as resistance heaters or incandescent lights, but typically read low when loads are non-linear. True-RMS multimeters use a root-mean-square calculation and calculate an effective value. True-RMS multimeters should be used on variable-speed motors.

MINIMUM VENTILATION

Minimum ventilation requirements change as pigs become larger. In order to assess the building and controller settings for minimum ventilation, the ventilation system was artificially set to the minimum rate using the ‘Test’ feature on the controller – whereby the inside air temperature was prescribed to be just below the set-point temperature. Several measurements were made during the short time period after the controller was put in test mode. Air temperature in the room rose at 0.6°C (1°F) per minute when the room was operated at the minimum controller setting. Relative humidity stabilized at 80%, while carbon dioxide, ammonia, and hydrogen sulfide concentrations were measured as 2500 ppm, 25 ppm, and less than 1 ppm, respectively. These measurements all indicate that the minimum rate was not sufficient for pigs of this size [91 kg (200 lb)] under the observed outdoor conditions [sunny, light winds from NW, and 1°C (34°F)]. The static pressure difference between the room and outdoors was measured to be 15 Pa (0.062 in. H₂O) through an opening in the curtain. This is an acceptable level for normal operation. Approximate average air velocity measured at inlet openings with the Kestrel® 3000 was 3.6 m/s (700 fpm).

The ceiling inlets were self-regulating, using a counterweight system that responded to changes in ventilation rate. Weights on the inlets should be adjusted in a way that creates appropriate static pressure differences that thereby create proper inlet air speed. As more fans are activated the inlets respond by opening more. At minimum ventilation, all the inlet opening areas were measured. Opening widths ranged from 1.6 to 3.8 cm (0.625 to 1.5 in.) with an average width of 2.3 cm (0.91 in.). The variation was due to unplanned differences in counter-weight and stop adjustments.

In order to estimate the minimum ventilation rate, Q_{\min} , the inlet velocity and inlet area were combined as shown in equation 1. The vena contracta effect, and therefore the

discharge coefficient, was neglected because it was felt that due to the size of the Kestrel® 3000 wind speed sensor relative to the inlet opening, the velocity measured was the average inlet velocity rather than the vena contracta velocity. The inlet baffles also did not approximate a sharp-edged orifice due to smoother transitions and leakage through cracks around the building shell was unaccounted for in the calculations. These factors indicate that equation 1 serves as only an approximation for field estimations and is not appropriate for research.

$$Q = \text{Number of inlet openings} \times \text{average opening width} \times \text{opening length} \times \text{inlet airspeed} \quad (1)$$

$$Q_{\min} = (12 \times 2) \times 0.023 \text{ m} \times 0.61 \text{ m} \times 3.6 \text{ m/s} \\ = 1.2 \text{ m}^3/\text{s} \text{ or } 4.3 \text{ m}^3/\text{h-pig}$$

$$(Q_{\min} = 24 \times (0.91 \text{ in} \times 24 \text{ in}) \times (1 \text{ ft}^2/144 \text{ in}^2) \times \\ 700 \text{ ft/min} = 2,550 \text{ ft}^3/\text{min} \text{ or } 2.5 \text{ cfm/pig})$$

MWPS (1983) recommends a minimum ventilation rate of 17 m³/h-pig (10 cfm/pig) for pigs larger than 68 kg (150 lb). The minimum air exchange rate provided at the time of analysis was estimated at about one-quarter of the appropriate rate. The relative humidity of 80% and elevated carbon dioxide and ammonia levels also indicated that the facility was under-ventilated at the time of the test. The conclusion drawn was that the variable-speed fan output at the minimum setting was too low for pigs of this size and had not been changed as pigs grew. The minimum ventilation rate should be increased as pigs grow larger in order to maintain good air quality during cold weather. This rate is over-ridden when temperature increases above setpoint in the room and the controller increases ventilation.

Selecting a proper minimum percentage for variable-speed fans is a complex task. The percentage displayed by the controller does not necessarily indicate percentage of full airflow capacity. Motor curves are specific to a type of fan and motor combination and translate the percentage that is displayed on the controller panel to a voltage which is provided to the fan. A check of guidelines for different types and sizes of fan motors showed that the controller for the APP24F fans should be set on motor curve 4. In this case the motor curve was properly selected, but improper selection is common. Controllers can have as many as ten motor curves available to match with available variable-speed fans. Variable-speed fans respond differently to given supply input waveforms, and the resulting fan speed depends upon motor design and fan characteristics.

During the site visit, voltages were recorded for each motor curve at various controller percentage settings using a true-RMS multimeter. Measured voltage output with six of the ten motor curves is recorded in table 3. Noteworthy were the relation of voltage and the rate of change of voltage as a function of input percentage for each curve. Note that, for example, a controller panel setting of 60% resulted in a wide range of voltage outputs (99 to 169 V) and did not necessarily correspond to 60% voltage delivered to the fan motor. Selection of an appropriate motor curve is generally done in consultation with the fan manufacturer. In this case, the minimum setting (curve 4, 60%) corresponded to a delivered voltage of 142 V from a 245-V supply (or 58% of supply voltage). The airflow delivered to the room, though, was estimated at 20% of total stage 1 capacity (1.2 out of 6.2 m³/s) and about one-fourth the rate desired to achieve adequate conditions during minimum ventilation for this size pig. This

Table 3. Measured voltages sent to variable-speed fans at various variable fan speed settings for six of the ten available motor curve settings in the TC5-IN8FA controller.

Variable Fan Speed (%)	Motor Curve Number					
	1	2	3	4	5	6
100	245	245	245	245	245	245
90	141	166	182	186	220	192
80	128	145	147	173	205	166
70	113	130	136	156	189	156
60	99	115	123	142	169	146
50	---	---	---	126	149	137
40	---	---	---	---	130	---

could indicate an improper minimum setting but may only be a part of the overall solution. Adjusting the minimum percentage to achieve targeted air quality of 50% to 60% relative humidity and ammonia at 25 ppm or lower would be a more appropriate approach. Widening the bandwidth from 0.5°C to 1°C (1°F to 2°F) would also make the increase in ventilation rate more gradual.

INLET MANAGEMENT

A cursory comparison of the total inlet capacity of 63.6 m³/h-pig (37.3 cfm/pig) to the total fan capacity, 59.6 m³/h (35.6 cfm) would indicate that the system is sufficiently matched. To examine this, all five fans were turned on and the inlet velocity was measured. While taking measurements, we noted that the producer had inserted stops to prevent inlets from opening wider than 8.9 cm (3.5 in.) to keep them from 'bouncing'; a common problem with self-regulating inlets in windy conditions. Actuated inlets have become more widely used to avoid the bouncing problem. With the stops in place and all five fans operating at full speed, the average inlet velocity was approximately 7.2 m/s (1,420 fpm) with static pressure in excess of 31 Pa (0.125 in. w.g.). Using equation 1 to calculate airflow rate through the inlets resulted in the following:

$$Q = 24 \times 0.089 \text{ m} \times 0.61 \text{ m} \times 7.2 \text{ m/s} = 9.4 \text{ m}^3/\text{s} \\ \text{or } 33.8 \text{ m}^3/\text{h-pig}$$

$$(Q = 24 \times (3.5 \text{ in.} \times 24 \text{ in.})/(144 \text{ in.}^2/\text{ft}^2) \times 1,420 \text{ fpm} = \\ 19,900 \text{ cfm or } 19.9 \text{ cfm/pig})$$

Use of the stops on the inlets severely limited the operating capabilities of the ventilation system. With the stops in place, the inlets were only capable of supplying enough airflow for three of the five fans without causing static pressure differences higher than normal operating ranges (>31 Pa). When fans operate at a higher static pressure the flowrate is decreased and more power is required, thereby causing higher electrical usage. Other restrictions, such as those created by restricted attic openings or fan mounting transition openings between the fan and the building would have similar effects. Furthermore, because the ventilation system was hampered by restricted inlets, the ventilation rate did not meet the level required for heat balance which caused the temperature to rise faster than it would with an appropriate inlet capacity. This caused the ventilation curtain to begin to open prematurely when the outdoor temperature was cooler than what would have occurred in a normally operating facility. Opening the curtain to engage natural ventilation when the outside temperature is below 10°C (50°F), depending on pig size, can cause pigs to be chilled more easily, especially in windy conditions. The designed fan

capacity in this facility (59.6 m³/h-pig or 35.6 cfm/pig) was within the normal range for recommended fan capacity to delay the transition to natural ventilation until warmer outdoor temperatures are encountered. Hoff et al. (2009) stated that typical Midwestern swine industry design practices for fan capacity in this type of building range from 34 to 50 m³/h-pig (20 to 30 cfm/pig). Brumm et al. (2000) recommended 59.5 m³/h-pig (35 cfm/pig) but the latest industry practices are 62.9 to 71.4 m³/h-pig (37 to 42 cfm/pig) for new construction (Daggett, 2011).

STAGING OF FANS

The fan system should be designed such that it can be adjusted to the changing needs of pigs as they grow. The recommended minimum ventilation rate for pigs entering a finishing building at 27 kg (60 lb) is 5.1 m³/h-pig (3 cfm/pig) and increases to 17 m³/h-pig (10 cfm/pig) when pigs exceed 68 kg (150 lb) (MWPS, 1983). The use of variable speed fans allows for this adjustment. When animals are small one might question why only one fan could not be used for minimum ventilation. However, experience shows that in a room that is this long (61 m or 200 ft), a solitary fan may cause air quality gradients between the ends and the middle of the room even if it were centrally located.

A normal progression of ventilation fan staging should use smaller steps for the first stages and larger steps for later stages. As a general rule of thumb, an added fan stage should not more than double the previous ventilation rate. In this case, the second stage doubled the ventilation rate (see table 1) because the second stage was being treated as a single-speed stage. This can create excessive temperature fluctuations during cool weather. Two options were available to improve this situation. The second stage could be programmed to start at a lower speed than the current 100% or stages 2 and 3 could be switched so a single fan would operate with stage 2 and two fans with stage 3. In this case it worked well to switch stage 3, which was a single wall fan, with stage 2, which included two pit fans. This change resulted in steps that started at 23.8 m³/h-pig (14 cfm/pig) when stage 1 reached maximum speed, to 35.9 m³/h-pig (21 cfm/pig) when stage 2 was activated, an increase of only 50% rather than a 100% increase, and then to 59.6 m³/h-pig (35.6 cfm/pig) with the stage 3 fans operating. These smaller steps should provide a more constant environment due to less frequent fan cycling. This approach was recommended over using the current stage 2 at a lower speed because it would avoid the possible interaction which could occur when stage 1 was operating at 100% and stage 2 was operating at a slower speed such as 50% for instance.

TEMPERATURE SETTINGS

Temperature settings can greatly affect heating fuel usage. The temperature setpoint on a controller is not the operating temperature; it is a reference temperature on which heating or cooling stages are based. Above the setpoint temperature variable-speed fans increase in speed to increase the ventilation rate and cool the building. Below the setpoint, heaters are used to maintain temperature. A common misconception is that the average room temperature is the same as the setpoint temperature, however during the heating season the room will operate slightly colder than setpoint and

during the cooling season the room will operate warmer than the setpoint.

Controllers generally have a heater differential setting, which is the temperature difference between when the heater starts and when it stops, and a heater offset, which is the temperature difference between the setpoint and the temperature at which the heater stops. The temperature of the room, as measured by the controller sensor, will often continue to increase slightly after the heater turns off, especially in a small room with a large heater. The offset is used to prevent the room temperature from surpassing the setpoint temperature (a condition commonly referred to as “heater run-by”), thereby preventing exhausting heat that was just added to the room. This situation in which the ventilation rate is increased immediately after heater disengagement will create rapid temperature cycling and significant heating fuel wastage.

The controller settings at the time of the farm visit used a setpoint temperature of 19.5°C (67°F), with the heater offset and differential set to 0.8°C and 0.5°C (1.5°F and 1°F), respectively. This means that the heater started when the room temperature dropped to 18.2°C (64.5°F) and operated until the room temperature reached 18.7°C (65.5°F). Therefore, the room temperature would fluctuate between 18.2°C and 18.7°C (64.5°C and 65.5°F) during heating cycles, assuming no heater run-by. Generally a heater offset of 0.8°C to 1.1°C (1.5°F to 2°F) and a differential of 0.5°C (1°F) are typically recommended by manufacturers as initial settings.

Setpoint temperature should be appropriate to the animal size and should be changed in response to growth. Animal posture is a good indication of proper setpoint temperature within a facility. Pigs that are side-by-side nearly touching are considered to be in the thermal comfort zone (Mount, 1968). Pigs that huddle but do not pile will be nearer the lower critical temperature while those spread farther apart with little touching would indicate a higher environmental temperature. The goal during cold weather is to operate at a temperature near the lower critical temperature which will have little impact on animal efficiency while conserving heating fuel. With experienced observations, a protocol for changing setpoint with pig size to maintain thermal comfort within a given facility may be developed. Some controllers have a “temperature curve” function that adjusts temperature based on the number of days pigs have been in the facility. This may also be done manually. Standard recommendations generally indicate changing temperature twice a week at first and weekly as pigs grow larger.

Because of the advanced size of the animals in the facility, a set-point temperature setting of 16.7°C or 17.8°C (62°F to 64°F) may be more appropriate than the setting encountered during the farm visit. This is supported by Hoff (2006) which gives an optimal effective environmental temperature range of 14.4°C and 17.88°C (58°F to 64°F) for 91-kg (200-lb) pigs. Cooling stages with water sprinkling and stir fans should also have been programmed to begin between 26.5°C and 29.5°C (80°F to 85°F) (MWPS, 1990b). Experience indicates that the lower range is more appropriate with current swine genetics.

SUMMARY AND CONCLUSION

Swine finishing facility ventilation is relatively complex and is often mismanaged. To learn to help producers better understand their ventilation systems, a team of university Extension specialists that included agricultural engineers and animal scientists spent a day carefully documenting conditions in a deep-pit swine finishing building with two 1,000-head rooms. Following the review of existing conditions and operating parameters, performance deficiencies were identified and recommendations were given regarding controller settings, inlet settings, and the transition to natural ventilation, with emphasis placed on making the ventilation system components operate in concert. The overall operating characteristics of the ventilation system and air quality in the animal space were documented, and ventilation and related management changes were discussed with the owner/operator by a multi-disciplinary team of specialists. The lessons learned from this exercise have helped our team of specialists develop educational resources for workshops conducted for livestock producers.

After analyzing the operation of the ventilation systems at the facility studied, the following recommendations were made:

- For minimum ventilation, the controller motor curve was appropriately set as per manufacturer recommendation to properly match the fan used for stage 1. The minimum speed percentage setting should be adjusted (increased) for animal size, and the bandwidth should be widened to 1°C (2°F). These changes should result in a more appropriate minimum airflow rate and would cause the system to respond more slowly and ramp the ventilation rate more appropriately. This controller is programmable and can be set to change the minimum speed of stage 1 based on the number of days since pig placement. If such an option is not available, weekly adjustments should be made manually to maintain air quality as pigs become larger.
- Discontinue the use of stops on the inlets. Simple things such as ventilation stops can severely limit ventilation capacity during warm weather and cause ventilation curtains to open at cooler ambient temperatures than desired. Having similarly rated capacities of fans and inlets does not guarantee compatible operation. Adjust counter weights more uniformly.
- Stage fans to use with smaller steps (less capacity) during cold weather and larger steps (more fans and larger capacity) for warmer weather. This will produce a smoother transition in ventilation rates and therefore reduce temperature fluctuations.

- Examine heater offset and differential settings, setpoints, and cooling stage settings closely to conserve energy while providing appropriate heating and cooling. Use a temperature curve to adjust the setpoint as pigs grow and their thermal needs change. If such an option was not available on the controller temperature should be adjusted twice per week for the first few weeks and weekly thereafter.

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