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The Real World of Ventilation Troubleshooting: A Swine Case Study

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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. 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 in the pit and walls operated at various stages throughout the year as a negative-pressure ventilation system. A computerized controller activated exhaust fans, a ventilation curtain actuator, and heaters. Gravity 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 curtain management. The overall operating characteristics of the ventilation system and air quality in the animal space were documented ventilation and related management changes were discussed with the owner/operator.*

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

Introduction

Over the last 40 years, swine buildings have progressed from simple concrete floors with minimal shelter from the elements to sophisticated buildings offering a premium environment to optimize growth and efficiency. Ventilation control systems are critical elements of this system that are often misunderstood and mismanaged. 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 program to address pork producer needs. Educational needs were identified through discussions with producers and evaluation of comments provided by participants in ventilation workshops conducted by the team. Producer needs focus 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. This paper 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 objective of this paper is to illustrate the procedure used to evaluate swine ventilation systems and discuss typical problems encountered in these buildings.

Problem Description

Building Layout

The 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. The overall building was approximately 12.5 m (41 ft) wide by 124 m (408 ft) long. Each room was 12.5 m by 70 m (41 ft by 200 ft), with a workroom between the rooms. The building had a 2.4 m (8 ft) deep manure pit beneath a fully slatted floor.

Building construction was concrete below grade and steel over wood frame above grade. 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 m x 5.7 m) on either side of the aisle.

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

Ventilation System

The ventilation system was set up to use primarily mechanical ventilation in the winter and primarily natural ventilation in the summer. The mechanical system used ten exhaust fans – five per room. Each room had four fans mounted on the manure pit access ports (approximately 1.2 m by 1.2 m (4 ft by 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 equipped with discharge cones (GSI[1] Model APP-24F; Automated Production Systems, Assumption, IL) were 0.61 m (24 inches) in diameter and were equipped with discharge cones. The rated capacity (BESS, 2008) of these fans was 3.31 m^3/s (7,010 cfm) @ 12.5 Pa (0.05 inches w.g.). The fans were configured in stages as shown in Table 1.

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

Ventilation Stage	Number of Fans in Stage	Speed Variable?	Max. Stage Airflow	Accumulated Airflow	Accumulated 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/hr·pig (14.0 cfm/pig)
2	2	No	6.62 m^3/s (14,020 cfm)	13.2 m^3/s (28,040 cfm)	47.5 m^3/hr·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/hr·pig (35.6 cfm/pig)

Twelve gravity-controlled box inlets were evenly spaced over the center walkway of each room (Figure 2). Each box inlet directed airflow in two directions, to the north and to the south. The inlet capacity was rated by the manufacturer (Automated Production Systems, Assumption, IL) at 1.47 m^3/s (3,120 cfm), giving each room a total inlet capacity of 17.7 m^3/s (37,440 cfm) or 63.6 m^3/hr-pig (37.3 cfm/pig). Outdoor air entered the attic via eave openings along the south wall. The eave opening provided at least 9.3 m^2 (100 ft^2) for air intake and was determined to be sufficient to keep airspeed across the opening below the recommended maximum of 2 m/s (400 fpm).

Each room had 2 space heaters, with a capacity of more than 72 kW (250,000 Btu/hr) each. For cooling, eight basket fans were located along the south edge of the room pointed slightly downward and toward the north to provide convective cooling. For further cooling, water nozzles were located over each pen and cycled on and off to allow evaporation between wetting cycles. An adjustable curtain extended the length of the north and south walls for natural ventilation during warm room conditions. The sidewall opening was 1.5 m (5 ft) tall, beginning 0.6 m (2 ft) above the floor.

The ventilation controller, located in the workroom, was an Airstream TC5-IN8FA (Automated Production Systems, Assumption, IL). Two temperature probes were located at mid-points in the room 1.5 m (5 ft) above the floor. The controller used the average of the two probe readings for its control decisions.

[1] Mention of specific company names is for clarity and not intended as an endorsement.

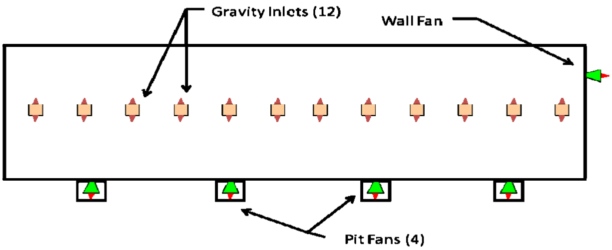

Figure 2. Ventilation layout for one room of the deep-pit swine finishing building (not to scale).

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 lbs), coming in at approximately 27 kg (60 lbs) and marketed at 124 kg (273 lbs). 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 lbs/day).

On the day of the farm visit, controller settings for the heating, cooling and ventilation stages were as shown in Table 2. At minimum ventilation, the controller was set with the intent that stage 1 fans would each deliver 60% of rated capacity or 2.0 m^3/s (4,200 cfm).

Table 2. Controller settings at the time of the assessment. Set-point temperature was 19.5 °C (67 °F).

Stage	ON Temperature	Other Stage Information
Heating	18 °C (64.5 °F)	OFF temperature: 18.6 °C (65.5 °F)
Fan stage 1, variable-speed	Continuous Capacity increased above 19.5 °C (67 °F) up to 20 °C (68 °F)	60% minimum setting (generally assumed to imply 60% of rated fan capacity) 100% at or above 20 °C (68 °F) Motor curve 4 (sets power delivery to fans)
Fan stage 2, single-speed	20.5 °C (69 °F)	0.5 °C (1 °F) differential from Stage 1
Fan stage 3, single-speed	21 °C (70 °F)	0.5 °C (1 °F) differential from Stage 2
Curtains	22 °C (71.5 °F)	Move for 15 s / wait for 120 s
Stir fans	28 °C (83 °F)	
Cooling: water sprinkling	31.5 °C (89 °F)	Cycled

Evaluation

Several facets of the ventilation system were evaluated during this field study. These include minimum ventilation rate, inlets settings, staging of fans, and temperature settings.

Minimum Ventilation

During this portion of the evaluation, ventilation was artificially set to minimum using the 'Test' feature on the controller – wherein 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 was 80%. Carbon dioxide, ammonia and hydrogen sulfide concentrations were 2500 ppm, 25 ppm, and less than 1 ppm, respectively. The static pressure in the room was measured at 15 Pa (0.062 inches H_2O). Air velocity measured at inlet openings was 3.6 m/s (700 fpm).

The ceiling inlets were self regulating on a counterweight system that responded to static pressure. At minimum ventilation, all the inlet opening areas were measured. Measured opening widths ranged from 1.6 to 3.8 cm (0.625 to 1.5 inches) with an average width of 2.3 cm (0.91 in). The openings on the 12 inlets were 61 cm (24 in) long on each side. In order to estimate the minimum ventilation rate, the inlet velocity and area were combined as shown in the equation below.

Q = Number of inlet openings x average opening width x opening length x inlet airspeed (1)

Q_{min} = (12 x 2) x 0.023 m x 0.61 m x 3.6 m/s = 1.2 m^3/s or 4.3 m^3/hr-pig

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

MWPS (1983) recommends a minimum ventilation rate of 17 m^3/hr-pig (10 cfm/pig) for pigs larger than 68 kg (150 lbs). The air exchange rate provided at the time of analysis was substantially less than the recommended rate. The relative humidity of 80% was also an indication that the facility was under-ventilated. The conclusion drawn was that the variable-speed fan output at the minimum setting was too low for pigs at this size. Adjusting the minimum ventilation setting above 60% would only be a partial solution to the problem in this case, though. A check of guidelines for different types and sizes of fan motors showed that the controller for these particular fans should be set on motor curve 5, but they were actually set on motor curve 4 within the controller. Motor curves are one common way for controllers to determine the voltage to be delivered to fans. Fans respond differently to given voltages, with the resulting fan speed depending upon motor design and fan characteristics. During the site visit, voltages were recorded for each motor curve at various controller percentage settings. Measured voltage output with six of the ten motor curves is recorded in Table 3. The main difference seen between these settings is the rate of change of voltage as a function of input percentage. Note that a read-out of 60% on the controller resulted in a wide range of voltage outputs (99 V to 169 V) and did not usually 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 240-volt supply (or 60% of supply voltage). The airflow delivered to the room, though, was only 20% of total stage 1 capacity (1.2 out of 6.2 m^3/s) and about one-fourth the rate desired at minimum ventilation. So, the assumption that the fans delivered 60% of rated airflow capacity at this setting was inherently flawed. Changing to motor curve 5 would provide 169 volts to the fans, resulting in more airflow at minimum ventilation. Using motor curve 5 would also allow for a more gradual increase in fan speed as room temperature warmed. Widening the bandwidth from 0.5 to 1 $^{\circ}$C (1 $^{\circ}$F to 2 $^{\circ}$F) would also help to make the increase in ventilation rate more gradual.

Table 3. Measured voltages sent to variable-speed fans at various % settings for six motor curves in the TC5-IN8FA controller.

	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	---

Inlet Settings

A cursory comparison of the total inlet capacity of 63.6 m^3/hr-pig (37.3 cfm/pig) to the total fan capacity, 59.6 m^3/hr (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’ in windy conditions, a common problem with self-regulating inlets. With the stops in place and all five fans operating at full speed, the 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_{min} = 24 x 0.089 m x 0.61 m x 7.2 m/s = 9.4 m^3/s or 33.8 m^3/hr-pig
(Q_{min} = 24 x (3.5 in x 24 in)/(144 in^2/ft^2) x 1,420 fpm = 19,900 cfm or 19.9 cfm/pig)

Use of the stops on the inlets severely limited the capacity of the ventilation system. The existing inlet capacity could have been matched with only three of the five fans operating, rendering the last two fans ineffective. The restricting of inlets also worked the fans harder, causing higher electrical costs. Restrictions created by dirty fans, restricted attic openings or fan transition openings would have this same effect. Furthermore, because the ventilation system was hampered by a restriction in the inlets, the temperature would rise much faster than it would with more inlet capacity, and the ventilation curtain would begin to drop at cooler outside temperatures than what would have been intended. With the fan capacity in place on this operation (well in excess of minimum), a recommended tactic would be to delay the drop in curtains until the temperature was 10 $^{\circ}$C (50 $^{\circ}$F) or warmer to prevent chilling of pigs in windy conditions.

Staging of Fans

A normal progression of ventilation staging should use smaller steps for the first stages and larger steps for later stages. In this case, the second stage doubled the ventilation rate (see Table 1). This created an environment that varied considerably during cool conditions and, on occasions, would cycle very frequently. It made more sense to switch stage 3, which was a single wall fan, with stage 2, which included two pit fans. This change would result in steps that go from 23.8 m^3/hr-pig (14 cfm/pig) when stage 1 reached maximum speed, to 35.9 m^3/hr-pig (21 cfm/pig) for stage 2, an increase of only 50 percent rather than a 100 percent increase, to 59.6 m^3/hr-pig (35.6 cfm/pig) with the stage 3 fans operating. These smaller steps should provide a more stable environment due to less frequent fan cycling.

Temperature Settings

Temperature settings can make a big difference in heating fuel usage. The temperature on a controller is not the operational temperature, but it is a temperature by which heating or cooling is triggered. The settings at the time of the audit used a set-point temperature of 19.5 °C (67 °F). With the heater offset and differential being set at 0.8 °C and 0.5 °C (1.5 °F and 1 °F), respectively, this meant the operating temperature would fluctuate between 18.2 and 19 °C (64.5 and 66 °F) during heating and above set point during cooling. Because of the advanced size of the animals in the facility, a set-point temperature setting of 16.7 or 17.8 °C (62 to 64 °F) may be more appropriate. Cooling stages should also have been started at 26.5 °C (80 °C).

Summary and Conclusion

To learn to help producers better understand their ventilation systems, a team of university Extension specialists that included agricultural engineers and animal scientists spent an extended period carefully documenting conditions within 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 curtain management. 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 study facility, the following recommendations were made:

- For minimum ventilation, the motor curve should be changed, the minimum speed 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.
- Discontinue the use of stops on the inlets. Simple things such as ventilation stops can severely limit ventilation capacity and cause ventilation curtains to open at lower ambient temperatures than desired. Having similarly rated capacities of fans and inlets does not guarantee compatible operation.
- Stage fans with smaller stages during cold weather and larger stages for warmer weather.
- Examine temperature settings closely to conserve energy while providing appropriate heating and cooling.

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