RESEARCHREPORT

ENVIRONMENT

Title: Air Quality/Emission and Energy Usage Impacts of No Pit fans in a Wean to Finish Deep Pit Pig Facility. - **NPB #07-042**

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Institution: University of Minnesota

Date Submitted: Feb 27, 2009

Industry Summary:

The primary objective of this project was to document the air quality impact (both barn air quality and gas emissions) through a simple modification to the ventilation system of deep-pit, pig finishing buildings that are typically used in the Midwest. This simple change was the moving of the minimum ventilation fans from the pit pumpout to the building sidewall. This modification was done to one room of a "doublewide" 2800-head, deep-pitted, mechanically-ventilated grow finish barn in Western Minnesota. This barn had two identical rooms housing 1400 pigs each. For this investigation the South Room (SR) pit fans were moved into the sidewalls while the pit fans were left on the pumpouts in the North Room (NR). Monitoring of several air quality parameters was done continuously for 6 months (covering two separate batches of pigs).

Results suggest that when airflow rates in the rooms are similar, this simple change in ventilation design did not have a negative impact on barn air quality and reduced emissions of ammonia (NH_3) slightly (25%) and hydrogen sulfide (H_2S) considerably (75%). The differences in NH_3 and H_2S emissions between rooms with and without pit fans seem to be highly related to the level of manure in the under the barn pit. This was shown by the dramatic reductions in hydrogen sulfide emissions after manure pumping (from both rooms) which lowered the manure level. Ongoing monitoring and data analysis will be used to confirm these initial findings.

A secondary objective of the study was to determine the energy and nitrogen conservation impacts when this ventilation design change (elimination of pit fans in deep-pit barns) was implemented. Tentatively, moving minimum ventilation fans from the pit to the wall should reduce electrical energy usage by fan since fewer and more energy efficient fans can be used and fans exhausting air through the barn wall typically have less pressure drop (and thus less energy use) than fans exhausting air through the pit. The use of LP Gas or other fuels to provide supplement heat in these barns with and without pit fans is still being evaluated for our second (winter) group of pigs. Again, if similar airflow rates are maintained, it seems doubtful that additional fuel usage will be required in a barn without pit fans. Also, if NH_3 emissions (N loss) can be reduced from a barn without pit fans, the manure will retain more nitrogen, which should be a benefit to producer utilizing these nutrients as crop nutrients.

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III. Scientific Abstract:

Ammonia (NH_3) and hydrogen sulfide (H_2S) Flux rates (FR) from both rooms of a 2800 head double-wide, deep-pitted, mechanically-ventilated, grow-finish barn were monitored continuously for approximately six months. A wean to finish barn was desired but a suitable cooperator with such a barn could not be located. The two rooms (north and south) were identical except that the south room (SR) pit fans were moved from manure pumpouts into the sidewall prior to monitoring. Additionally, there was some offset (≈ 2 weeks) in the filling and emptying of the pigs as noted in the data. Concentrations of NH_3, H_2S and carbon dioxide (CO_2) were measured at 6 locations per room every two hours using EPA approved instrumentation. Room pressure (PA) and temperature (°C) and humidity (%RH) were monitored continuously along with ambient (outside) temperature and humidity. Monitoring included both warm and cold weather, beginning in September of 2008 and will continue through March 2009. NH_3 and H_2S FR ($\mu g/s/m^2$) varied widely and are reported pre- and post-pumping of the manure pit. In general, moving the pit fan from the pit pump out to the sidewall reduced ammonia emissions from the barn by 20% and hydrogen sulfide by 80% without any real impacts on indoor air quality in the barn for the first group or turn of pigs.

Keywords: Aerial emission, ventilation, pig grow-finish barns

IV. Introduction:

Pig production buildings create a variety of airborne contaminants (gases, odor, and dust) that produces indoor air quality concerns for workers and animals as well as generating airborne emissions of these same aerosols through either the exhaust fans of mechanically ventilated barns or through the ridge vents and sidewalls of naturally ventilated or curtain-sided buildings. These indoor air quality and emission issues are of particular concern in pig facilities where manure is stored commonly stored in deep pits (typically eight feet deep) under the floor of the barn that is only separated from the animal and worker area by concrete slats (≈ 20% open). Deep-pitted pig buildings are the standard housing systems for Midwestern U.S. pig nursery and grow-finish facilities.

Some of these airborne contaminants are hazardous compounds as defined by the Environmental Protection Agency (EPA), such as ammonia (NH_3) and hydrogen sulfide (H_2S), which create chronic indoor air health concerns for workers (Rylander, et al., 1989) and for the pigs housed (Jacobson, et al., 1996). The Occupational Safety and Health Act (OSHA) currently limit indoor workplace exposure of both NH_3 and H_2S for entities with more than 10 employees. Also, airborne pollutants, like particulate matter under 10 μm in aerodynamic diameter (PM_{10}), can create environmental ambient air quality concerns when they are released into the atmosphere. As a results of these health and environmental concerns, the airborne emissions of some of these pollutants (NH_3, H_2S, and PM_{10}) are now being regulated by not only states statues (such as in Minnesota and Iowa) but also by the federal EPA through the notification provisions of both the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act (EPCRA) plus the Clean Air Act (CAA) that is part of the EPA air quality consent agreement. Finally, many of these airborne compounds are also odorous, which negatively impacts neighbors making it difficult to site new facilities and in some case to operate existing barns. Thus, there is a need to know the amount of these pollutants being emitted from pig production buildings for simple regulatory purposes, but more importantly to determine how these airborne pollutants can be reduced to levels that will meet the regulatory limits, lower the impact of odors for neighbors, and minimize the risk to workers and pigs.

One commonly reported indoor air contaminate in pig barns is ammonia. Typical NH_3 concentrations in well-ventilated swine buildings with liquid manure systems are 5 to 10 ppm and 10 to 20 ppm where manure and urine are deposited on solid floors (Jacobson, et al., 1996). Meyer and Bundy (1991) surveyed 200 swine-farrowing houses and determined that the average NH_3 concentration was 11.4 ppm from December to February and 6.9 ppm from March to May.

Another gas pollutant of concern is hydrogen sulfide. H_2S is formed in pig buildings by bacterial sulfate reduction and the decomposition of sulfur-containing organic compounds in manure under anaerobic conditions such as in deep pits (Arogo et al., 2000). H_2S can be detected at very low concentrations (30 ppb) by over 80% of the population (Schiffman et al., 2002). Typically in well ventilated and managed pig buildings, the concentration of H_2S will be less than 1 ppm. Hydrogen sulfide was measured at 90 ppb in a well ventilated pig building and 280 ppb after the ventilation was shut off for six hours (Muehling, 1970).

Finally, one of the most commonly mentioned management practices to deal with the indoor air quality issue in deep pit pig barns is the use of pit exhaust fans. The MidWest Plan Service (MWPS-32, 1990) mechanical ventilation handbook recommends that "at least the cold weather rate but no more than the mild weather rate of a barn's ventilation airflow" be provided by pit fans. Unfortunately, the MWPS pit fan recommendation for deep pitted barn is NOT based on any known research results but rather on what seems to be a logical assumption that air exhausted from the pit area would remove more of the airborne contaminants (gases and odors especially) from the building and thus improve the indoor air quality in the barn compared to air removed by wall mounted fans.

V. Objectives

This project's primary objective was to document the air quality (indoor gas concentrations and emission from the barn) of relocating pit ventilation fans in a deep pitted finishing barn to the side wall (have no pit fans). Other objectives were to document impacts on pigs and energy use as a result of this change.

VI. Materials and Methods

Gas emission monitoring was done on a 2800-head capacity, deep-pitted, mechanically ventilated grow-finish pig site in West-Central Minnesota. This style of building is very common in Minnesota and the Midwest. The barn was 104' x 240' with a divider wall down the middle creating two rooms 50' x 223'. Each of these rooms had 14 pens holding 100 pigs per pen. Each room had an independent ventilation system with ceiling inlets (Model PFA134001 temperature actuated 17" x 34",) for winter ventilation and an endwall curtain (4.5' x 43, temperature actuated) for summer tunnel ventilation. Inlets, curtains, fans and heaters were controlled by a Phason^{TM} controller using temperature setpoints. 1st and 2nd stage ventilation was provided by 4-24" diameter blade, direct-drive fans (Multifan V6E6308M60100, Bloomington, IL). These fans were located in the pit pumpouts on the north room (NR) and in the sidewalls in the south room (SR). The other four ventilation stages were provided by two 36" diameter blade, direct-drive fans (J&D Manufacturing, #VFP36S, Eau Claire, WI) and five 52" diameter blade, belt driven fans (J&D manufacturing #VFP50AC, Eau Claire, WI)) installed on the east end of each room. Total fan capacity for each room was approximately 138,000 cubic feet per minute (cfm).

Gas Concentrations, Temperature and Humidity

Environmental monitoring began on September 29, 2008 in both the SR and NR. Rooms will be monitored through the end of March, 2009 to allow for monitoring of two complete groups (turns) of grow-finish pigs. Sampling lines were installed to collect air from five locations in each room and two locations (total of 12) representing the inlet air (attic space and endwall curtain). Air was pulled continuously through individual Teflon^{TM} sampling lines (heated lines between instrumentation trailer and building). All samples had a particle filter on the inlet end to prevent dust from entering the gas analyzers. A positive pressure Gas Sampling System (GSS), controlled by Labview^{TM} software, used solenoids to route air samples to the analyzers for a 10 minute sampling period per sample. Air flow through the sampling lines was maintained above 4 L/m. This resulted in each sampling location being evaluated for NH_3, H_2S, and CO_2 concentrations every two hours throughout the day. Ammonia concentration was determined using a TEI 17C ammonia analyzer, Thermo Scientific, Waltham, MA), Hydrogen sulfide concentration measured using a TEI 450i hydrogen sulfide analyzer (Thermo Scientific, Waltham, MA) and CO_2 concentrations made using and MSA #3600 Analyzer (MSA NorthAmerica, Pittsburg, PA). A TEI 55C (Thermo Scientific, Waltham, MA) methane analyzer was used for a four week period during the second group of pigs. Calibrations of these instruments were done approximately every 10 days according to Standard Operating Procedures outlined by the National Air Emissions Monitoring Project (https://engineering.purdue.edu/~odor/NAEMS/).

Temperature measurements were made at each sampling location and in the ambient air near the instrument trailer every minute using thermocouple wires. Relative humidity (%) was measured in each room and in the ambient air using a Vaisala #MHW61Y, (Vantaa, Finland). Static pressure in each room was monitored using a Model 260 Setra pressure transducer (Boxborough MA) and Labview^{TM} version 6.0 (National Instruments) was used to control the sampling sequence and record data.

Figure 1 shows a photo of the east (fan) end of the barn and the instrumentation trailer. Figure 2 shows a general layout of the barns with sampling points indicated.

Figure 1. Barn photo.

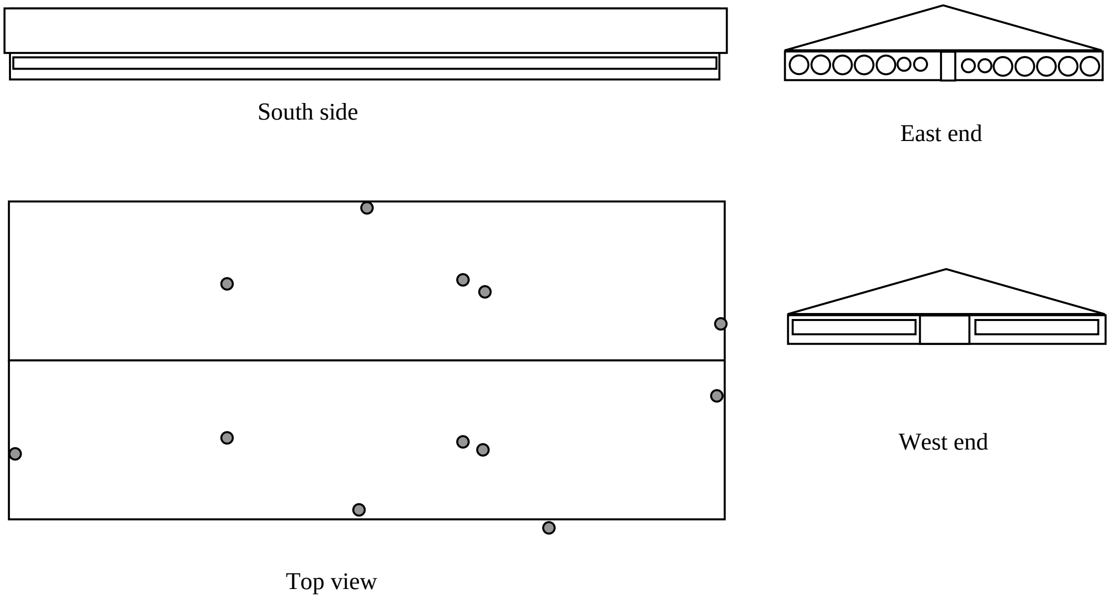

Figure 2. Schematic of barn and approximate location of sampling points.

Ventilation and Emission Measurements

All building exhaust fans were tested using a Fan Assessment Numeration System or (FANS) testing unit (Gates et al, 2005). Monitoring of fan on and off time was done using a current switch attached at the ventilation controller. Table 1 shows the resulting equations used to estimate airflow for each of the fans. Airflow measurements for each fan were calculated using the building static pressure (recorded every minute) and the appropriate fan curve equation. Maximum airflow with all fans operating at 0.05 inches of water gauge is approximately 138,000 cfm or about 100 cfm per pig. Note that the 24-inch fans in the SR had airflow rates from 30 to 40% more than the same fans in the north side because of their placement in the wall without a shroud instead of on top of the pit pump out cover with a shroud.

Table 1. Fan Airflow (y= airflow in cfm, x = pressure in Pascals)

Fan Size	Number/room	Equation	cfm/watt @0.05 inch
24-inch	4	$y = -0.5595x^2 + 1.5277x + 7621.4$ $r^2=0.85$ (SR) $y = -0.6328x^2 + 10.434x + 5358.7$ $r^2=0.77$ (NR)	8.7
36-inch	2	$y = -0.1486x^2 - 93.715x + 9455.6 r^2=0.79$ (SR) $y = 0.0227x^2 - 91.136x + 8888.8$ $r^2=0.98$ (NR)	21.8
50 inch	5	$y = 0.0776x^2 - 177.11x + 19921$ $r^2=0.87$ (SR) $y = -2.1077x^2 - 61.228x + 20488$ $r^2=0.98$ (NR)	20.1

Heater on-off time was monitored using a thermocouple place in front of the heater. Heat-on was assumed when the temperature was over 30°C.

Barn Management

Pig weights were different in these rooms as the SR was filled on July 8, 2008 and the NR was filled on July 22, 2008. This resulted in a pig weight offset throughout the first monitoring period (concluded on November 6, 2008) of about 34 lbs/pig. The SR was emptied completely by October 27, 2008 and the NR was empty by Nov 8, 2008. During this first monitoring period the SR had initially 1395 pigs and the NR started with 1411 pigs. The pig diet during this monitoring period contained approximately 10-20% DDGS and had a protein content averaging 14%. Close out numbers for the first group of pigs indicate a rate of gain of 1.9 and 1.8 lbs/day for the NR and SR respectively. Death loss in the NR was 0.3% and in the SR was 3.4%. Although the difference in mortality between rooms is quite different it is still below (better than) the industry average of 4 to 5 %.

A second monitoring period began on December 2nd with pigs being filled in the SR first on 11/18/2008 and in the NR on 12/06/2008.

Flux Rate Calculations

Flux rate (mass/time/area) was calculated using the measured concentrations at the exhaust points and the corresponding airflow rates using the following equation.

$$FR = Q * C * \frac{w_m}{V_m} * \frac{T_{std}}{T_a} * \frac{1000}{A}$$

Where

FR = µg s^{-1} m^{-2}
Q= building ventilation rate (m^3 s^{-1}) (based on fan curve and static pressure(Pa))
C= concentration of gas (ppb)
w_m= molar weight of gas (NH_3 = 17.031 g $mole^{-1}$, H_2S = 34.07 g $mole^{-1}$)
V_m= molar volume of air at STP (0.022414 m^3 $mole^{-1}$)
Tstd= standard temperature 273.15 °K
T_a= absolute temp (°K) at sampling location (°C + 273.15)
A= room area (1050 m^2)

Fan on-off time was also monitored along with heater on-off time.

VII. Results

Detailed results are given in this report only for the first monitoring period (September 29 to November 6, 2008 - first group of pigs). Data from the second monitoring period (late November, 2008 to present) is still being evaluated but some generalizations regarding this data is included in this report.

Environmental Conditions

Mean outdoor temperature during the first monitoring period was 49° F (9.4° C) with a maximum temperature of 76° F (24.5° C) and a minimum temperature of 21° F (-6.1° C). Outside relative humidity averaged 67%. Room temperatures in both barns averaged 68° F (20° C) over the first monitoring period (average). Temperature of the manure pit headspace in the SR was 63° F (17° C) while the average temperature in the NR pit was 68° F (20° C). This is probably caused by the NR pit fans allowing warmer room air to move through the slats into the manure pit space.

Room ventilation rates were similar between rooms as is shown in Figure 3. Static pressure monitoring showed average pressure in both rooms of 0.07 inches (operating range is from 0.03 to 0.10 inches).

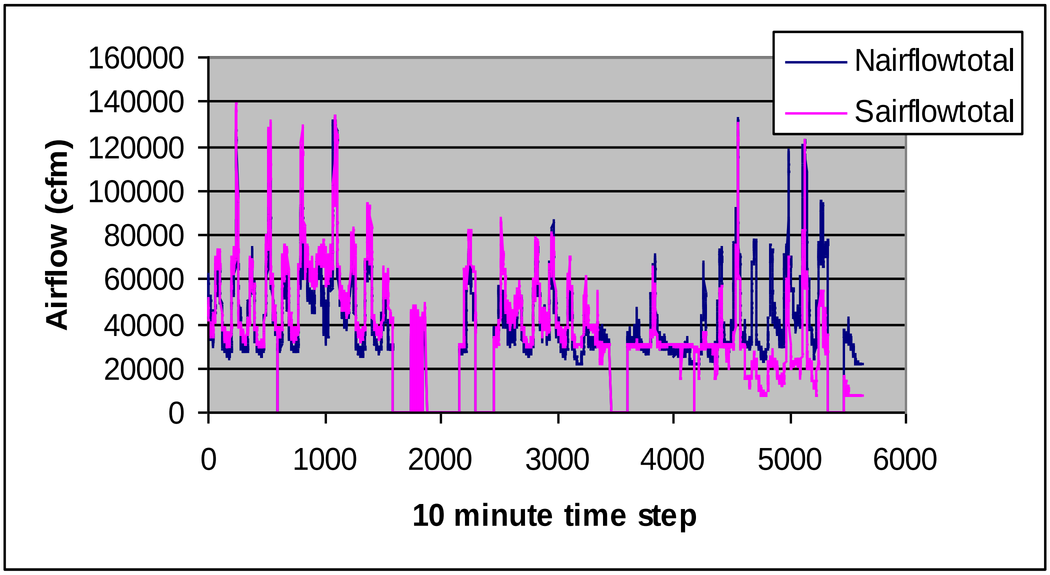

Figure 3. Ventilation rates for first pig group (Sept to Nov). Note that those points showing zero airflow are those times when the sampling/monitoring system was not in operation).

Gas concentrations

Daily mean concentrations of ammonia and hydrogen sulfide was higher in the NR at all matched locations (Table 1). The pit was pumped in October over several different days starting on October 4th in the South barn and ending on Oct 16th. Some of the pumpout activity can be seen in the monitoring data (dates shown on the graphs). Concentration and emission data for this first set of monitoring data is divided into pre- and post-pumping (Table 2).

Table 2. Average concentrations from first monitoring period for pre- and post-pit pumping from all sampling locations.

Description	**NH_3 ppm Mean (SD)**		**H_2S ppb Mean (SD)**		**T °C Mean (SD)**	**RH% Mean (SD)**
	Pre	Post	Pre	Post		
SR west end	6.6	16.5	328	53	19.5	-
NR west end	6.6	6.2	1057	96	20.2	-
SR middle	7.6	17.6	312	57	19.3	41
NR middle	7.3	8.3	1415	127	20.7	47
SR under slat	15.7	24.4	433	60	17.1	-
NR under slat	15.7	13.7	3854	232	20.4	-
SR sidewall fan	7.0	16.2	413	44	18.9	-
NR pit fan	22.8	24.7	2460	278	19.7	-
SR tunnel fan	9.8	17.0	264	46	17.2	-
NR Tunnel fan	7.1	7.6	1377	139	18.2	-
Attic space inlet	0.6	0.8	48	-9	-	
Inlet-Curtain	0.1	0.5	31	-5	-	-

Pre- includes data to October 4 and post- includes data after 10/17/2008

Flux Rates

Emissions per area or Flux rates (FR) are summarized in Table 3. Daily average FR of ammonia during pre pit pumping were 144 and 196 μg/s/m^2 in the SR and NR, respectively or a 25% reduction of NH_3 emissions in SR. Average FR for hydrogen sulfide prior to pit pumping was 12 and 54 μg/s/m^2 or about a 75% reduction.

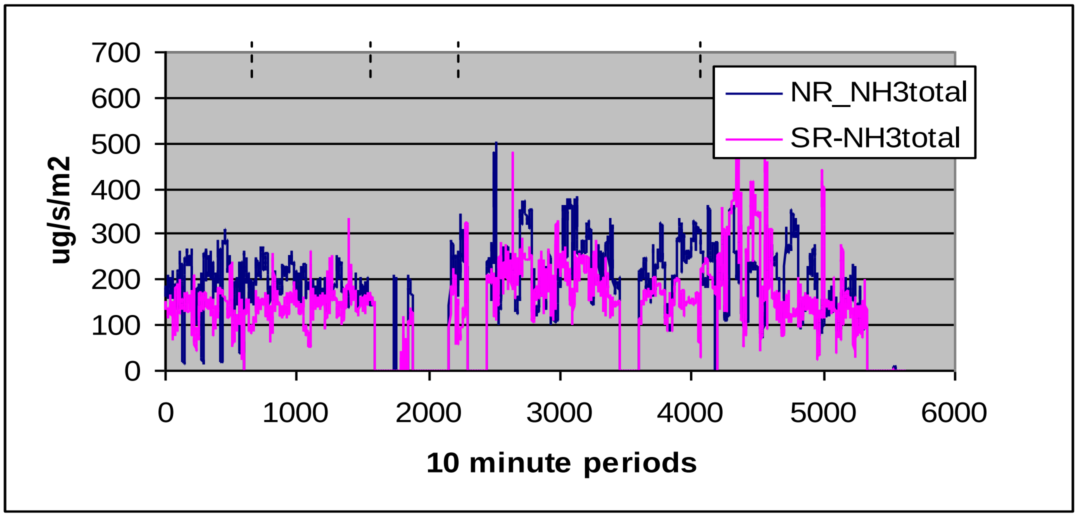

Figure 4. Graph of barn NH_3 flux rates for first monitoring period. First three dashed lines on top are pit pumping episodes while last line is when pigs were removed.

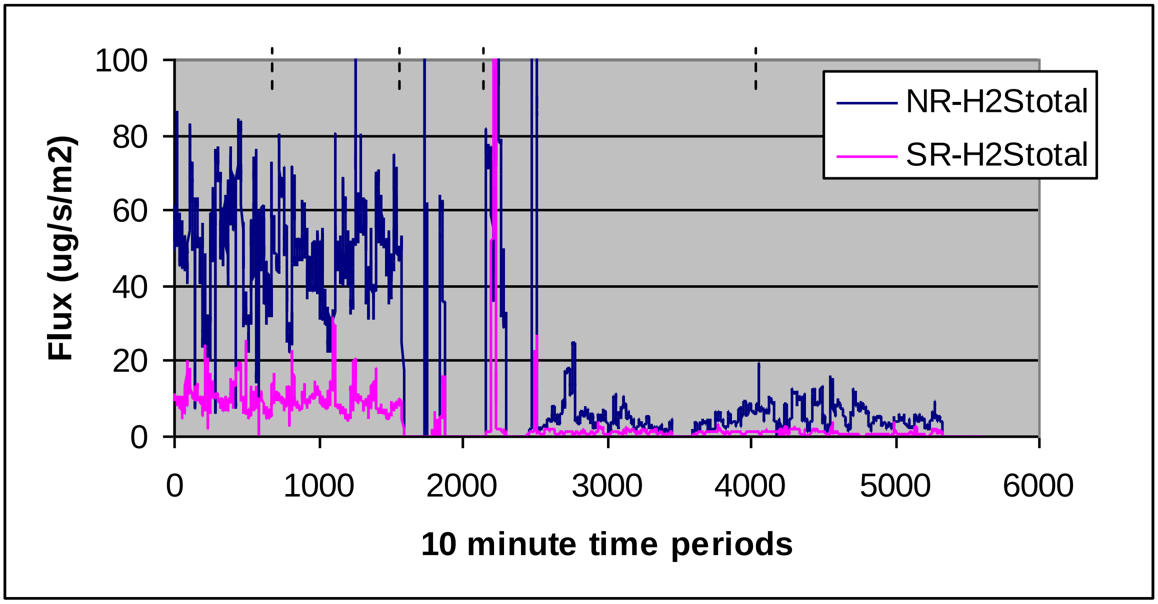

Figure 5. Graph of H_2S flux rates for first monitoring period. First three dashed lines on top of graph are pit pumping episodes while last line is when pigs from SR were removed.

Table 3. Average flux values from first monitoring period pre- and post-pit pumping.

	SRsidewall	NRpit	SRwall	NRwall	SRtotal	NRtotal
NH_3 prepump ($\mu g/s/m^2$)	92	145	52	51	144	196
NH_3 postpump ($\mu g/s/m^2$)	131	166	47	37	178	203
H_2S prepump ($\mu g/s/m^2$)	5	34	7	20	12	54
H_2S Postpump ($\mu g/s/m^2$)	0.8	3.8	0.3	1.3	1.1	5.1

Preliminary results from second group of pigs

Airflow or ventilation rates of the two rooms during the second group of pigs, unlike the first group, were quite different. Figure 6 shows the airflow rates for the two rooms (NR and SR) during the second group or turn of pigs. Consistently after the first few weeks, the SR airflow rates were roughly double those of the NR. Reasons for such a difference is that the SR was loaded first and pigs in this room where approximately 3 weeks + older and required more air exchange than the pigs in the NR. Also, because of the increased performance (30 to 40%) of the SR pit fans (when relocated in the sidewall) the fan staging had to be managed differently in the SR than in the NR. Both of these factors, plus possibly other winter ventilation issues, apparently resulted in the large ventilation rate differences seen in figure 6.

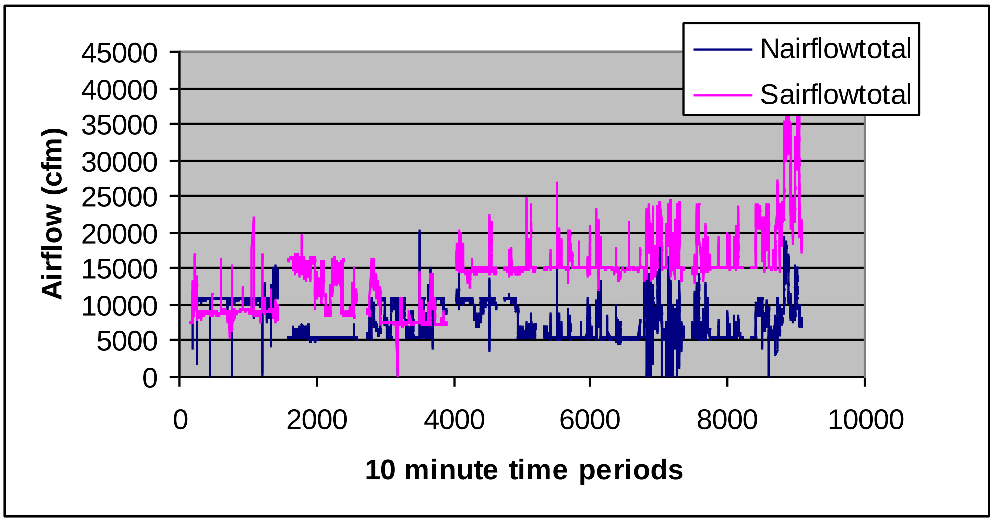

Figure 6. Ventilation rates for second group of pigs (late Nov to Feb)

The flux rates for NH_3 (Figure 7) and H_2S (Figure 8) are much higher in the SR (without pit fans) than in the NR (with pit fans), primarily due to the much higher ventilation rates, in the SR vs the NR during the second growth period. Although, NH_3 and H_2S concentration data at all sampling locations will be reported when the rooms are emptied in approximately a month, the gas levels (ppm) typically were similar and since emissions or flux rates are the product of concentrations and airflow rate this is probably accounts for these different results.

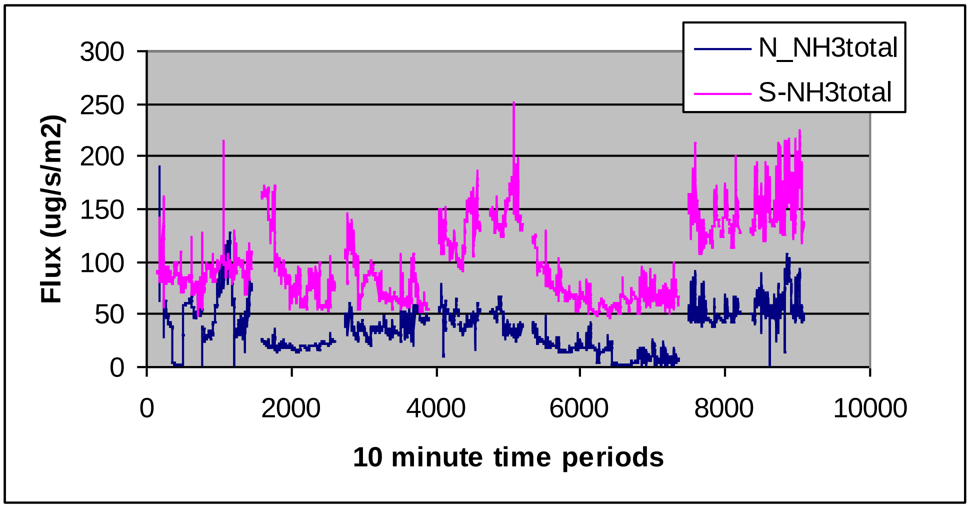

Figure 7. Ammonia (NH_3) flux rates for second group of pigs for the SR and NR

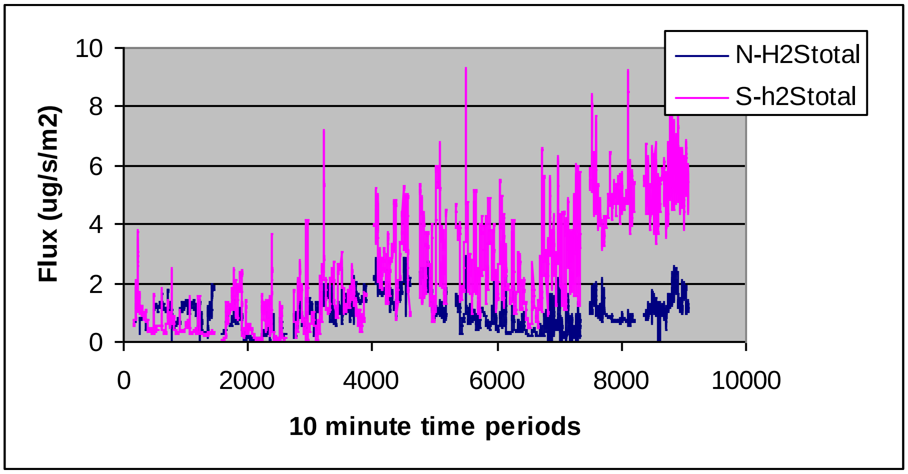

Figure 8. Hydrogen sulfide (H_2S) flux rates for second group of pigs for the SR & NR

Odor and Methane Emissions

Odor samples were taken on 10/23/08, 01/06/09, 02/03/09, and 02/23/09. Samples were taken in duplicate or triplicate from the exhaust points of the rooms and from the attic inlet as noted in Table 4. Odor emissions or flux rates (ou/s/m^2) for the SR on the four sampling dates were 7.0, 11.4, 6.9 and 11.1 while the odor flux rates from the NR were 21.8, 6.4, 6.6, and 10.2. The limited amount of odor data collected does not lend itself to a statistical analysis. However, simple observation of the numbers suggests that there is likely no real difference in odor concentrations or emissions from the two rooms.

Table 4. Odor Concentrations and Emissions

Date	Location	Concentration, ou/m^3 (multiple samples taken)	Airflow (cfm)	Flux (ou/s/m^2)
10/23/08	SR sidewall	595,591,399	29,700	7.0
	SR endwall	*No wall fans running*	-	
	NR pit	1449,1764	21,600	15.6
	NR wall	716,1175	14,600	6.2
	Attic Inlet	-	-	-
01/06/09	SR sidewall	1707,1148	12,100	7.8
	SR endwall	1143, 768	8,500	3.6
	NR pit	1145, 832, 942	13,400	6.4
	NR wall	*No wall fans running*	-	-
	Attic Inlet	111, 116	-	-
02/03/09	SR sidewall	1199,1006, 924	14,700	6.9
	SR endwall	*No wall fans running*		-
	NR pit	844, 847, 1170	15,500	6.6
	NR wall	*No wall fans running*	-	-
	Attic Inlet	61,63	-	-
02/23/09	SR sidewall	1834, 1193, 1834	15,200	11.1
	SR endwall	*No wall fans running*	-	-
	NR pit	776, 1194, 1997	17,300	10.2
	NR wall	*No wall fans running*	-	-
	Attic Inlet	38, 40	-	-

Methane concentrations were measured at all sampling points during the second batch of pigs for a four week period, starting 01/22/09. Average concentrations and emissions are reported in Table 5 for a two period (01/22/09 to 02/01/09). Note that although the concentrations are similar between locations and rooms (range of 15 to 24) the flux is quite variable because of the large dependence on airflow.

Table 5. Methane concentrations and flux during the second monitoring period.

Location	Concentration (ppm)	Flux (µg/s/m2)	Flux (g/d/pigspace)
SR side wall	17.1	276	18
SR end wall	15.3	33	2
NR pit	24.1	165	11
NR end wall	18.1	8	0.5

VIII. Discussion

The primary objective of this grant was to show the impact of eliminating the pit fan from pig grow-finishing buildings on indoor air quality and gas emissions. Monitoring results suggest that there is little impact on the barn's indoor air quality (gas, ammonia and methane concentrations, indoor temperatures, or relative humidity). However, this data also suggests that the change in fan placement (wall vs pit) would lead to approximately a 25% reduction in ammonia emissions and a 75% reduction in hydrogen sulfide emission. This reduction can best be seen in a plot of rank order emissions from the NR and SR (Figures 9 and 10). This rank order plot is necessary because of the nature of the data – quite variable over short periods of time. In a rank-order plot the emission data from each room was listed in ascending order and these two data sets were then plotted against each other.

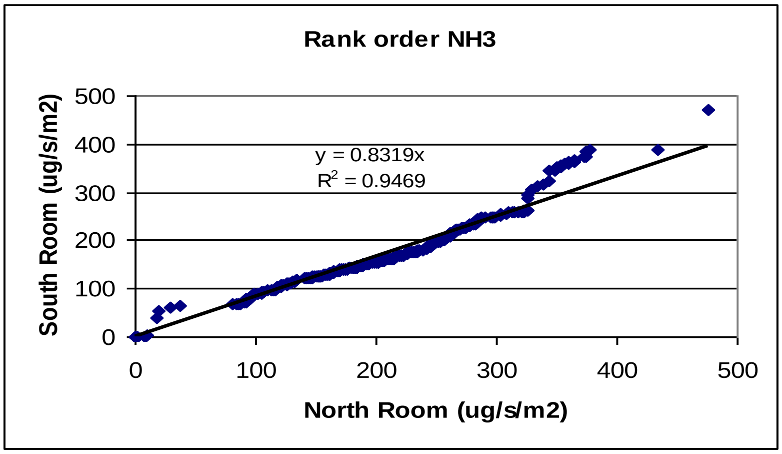

Figure 9. Rank order plot of ammonia emissions

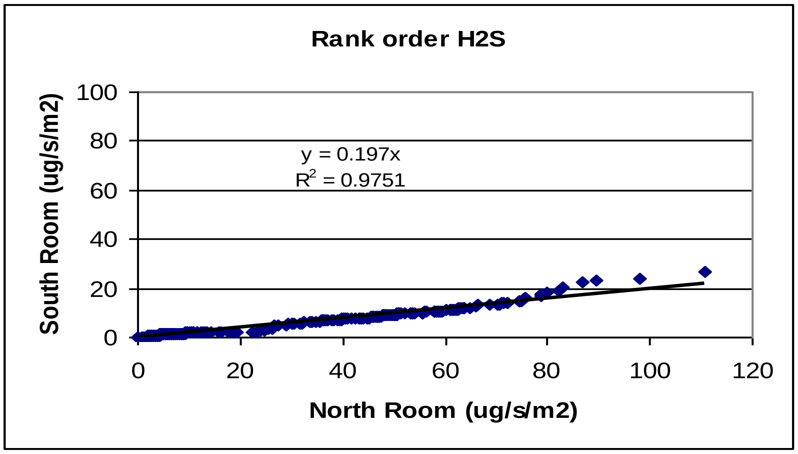

Figure 10. Rank order plot of hydrogen sulfide emissions.

The second objective of this study was to evaluate the energy impacts of this ventilation change. Unfortunately, the data set evaluated to date does not include heater (LP Gas) usage since no heat was used until the second monitoring period. Data from the second group of pigs (winter) being monitored will be evaluated for heater use. However, some conclusions can be drawn from the current set of data regarding fan usage. It is clear from the data that continuous running fans that provide the minimum ventilation rate are a necessary component of a pig finishing barn. The pit fans from the NR, which nearly always provided this minimum ventilation rate, operate at a poor cfm/watt rating – as reported in this study. Moving the minimum ventilation rate fans to the wall would allow for nearly 30,000 cfm of airflow to be supplied by more energy efficient fans (possibly larger diameter blade fans, i.e. 36”diameter blade fan). These fans have ratings closer to 20 cfm/watt (vs ~8 cfm/watt). At 30,000 cfm this change would result in energy use of 1500 watts vs 3750 watts.

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