An ASAE/CSAE Meeting Presentation *Paper Number: 044178*

Real-Time Ventilation Measurements from Mechanically Ventilated Livestock Buildings for Emission Rate Estimations

S.J. Hoff, D.S. Bundy, M.A. Huebner, B.C. Zelle

Iowa State University, ABE Dept, 212 Davidson Hall, Ames, IA 50011: hoffer@iastate.edu

L. D. Jacobson, B.P. Hetchler, V.J. Johnson, R.E. Nicolai, D.R. Schmidt, P.R. Goodrich

University of Minnesota, BAE Dept, 1390 Eckles Av, St.Paul, MN 55108; jacob007@umn.edu

A.J. Heber, J.Q. Ni, T.T. Lim, and P.C. Tao

Purdue University, Ag & Bio Eng, West Lafayette, IN 47907; heber@purdue.edu

Y.Zhang, J. McClure, S. Jerez, M. Roberts

University of Illinois, Ag. Eng. (Bioen & Eng Div), Urbana, IL 61801: yzhang1@uiuc.edu

J.A. Koziel, B.H. Baek, A. Balota, J.P. Spinhirne, J.M. Sweeten

Texas A&M University, Ag Res & Ed Ctr, Amarillo, TX 79106; ja-koziel@tamu.edu

D.B. Beasley, G.R. Baughman, R. Munilla

NC State University, Biological & Ag Eng, Raleigh, NC 27695; beasley@eos.ncsu.edu

Written for presentation at the
2004 ASAE/CSAE Annual International Meeting
Sponsored by ASAE/CSAE
Fairmont Chateau Laurier, The Westin, Government Centre
Ottawa, Ontario, Canada
1 - 4 August 2004

Abstract. *A six-state USDA-IFAFS funded research project (Aerial Pollutant Emissions from Confined Animal Buildings, APECAB) was conducted with the purpose of determining hydrogen sulfide, ammonia, PM10, and odor emission rates from selected swine and poultry housing systems. An important aspect of emission studies is to be able to measure the mass flow rate of air through the housing system. For this research project, the decision was made to study only fan ventilated buildings due to the difficulty in estimated mass flow rates through naturally ventilated buildings. This paper highlights the various techniques used throughout the study to determine mass flow rate through fan ventilated swine and poultry housing systems.*

Keywords. *Pigs, Poultry, Gas Emissions, Mass Flow Rate*

REAL-TIME VENTILATION MEASUREMENTS FROM MECHANICALLY VENTILATED LIVESTOCK BUILDINGS FOR EMISSION RATE ESTIMATIONS

S.J. Hoff, D.S. Bundy, M.A. Huebner, B.C. Zelle

Iowa State University, ABE Dept, 212 Davidson Hall, Ames, IA 50011: hoffer@iastate.edu

L. D. Jacobson, B.P. Hetchler, V.J. Johnson, R.E. Nicolai, D.R. Schmidt, P.R. Goodrich

University of Minnesota, BAE Dept, 1390 Eckles Av, St.Paul, MN 55108; jacob007@umn.edu

A.J. Heber, J.Q. Ni, T.T. Lim, and P.C. Tao

Purdue University, Ag & Bio Eng, West Lafayette, IN 47907; heber@purdue.edu

Y.Zhang, J. McClure, S. Jerez, M. Roberts

University of Illinois, Ag. Eng. (Bioen & Eng Div), Urbana, IL 61801: yzhang1@uiuc.edu

J.A. Koziel, B.H. Baek, A. Balota, J.P. Spinhirne, J.M. Sweeten

Texas A&M University, Ag Res & Ed Ctr, Amarillo, TX 79106; ja-koziel@tamu.edu

D.B. Beasley, G.R. Baughman, R. Munilla

NC State University, Biological & Ag Eng, Raleigh, NC 27695; beasley@eos.ncsu.edu

Abstract
A six-state USDA-IFAFS funded research project (Aerial Pollutant Emissions from Confined Animal Buildings, APECAB) was conducted with the purpose of determining hydrogen sulfide, ammonia, PM10, and odor emission rates from selected swine and poultry housing systems. An important aspect of emission studies is to be able to measure the mass flow rate of air through the housing system. For this research project, the decision was made to study only fan ventilated buildings due to the difficulty in estimating mass flow rates through naturally ventilated buildings. This paper highlights the various techniques used throughout the study to determine mass flow rate through fan ventilated swine and poultry housing systems.

Keywords. Pigs, Poultry, Gas Emissions, Mass Flow Rate

Introduction
A six-state USDA-IFAFS funded research project (Aerial Pollutant Emissions from Confined Animal Buildings, APECAB) was conducted with the purpose of determining hydrogen sulfide, ammonia, PM10, and odor emissions from selected swine and poultry housing systems in six regions throughout the United States. An important variable in emission studies is the mass flow rate of air through the housing system and this measurement can be challenging.

Several options exist for continuous measurement of airflow rate, although the accuracy and ease of use vary. The tracer gas method is a technique that has been used for years (Demmers *et al.*, 2000). This method uses an inert gas to predict the dilution potential of the ventilated space and through back calculation procedures the barns exchange rate can be determined. This method suffers from inaccuracy when there is incomplete mixing and is very instrument intensive. The tracer gas method is however the only currently available method for naturally ventilated livestock housing systems but in most situations is not accurate enough for emission studies. Another option for measuring airflow rate is using a frictionless anemometer that is just smaller than the fan size itself (Maghirang *et al.*, 1998; Berckmans *et al.*, 1991). This method has shown to work well for fans below 41 cm in diameter. Installations for the more common larger fans however suffered from excessive pressure drop that required the installation of a small duct section upstream of the fan, which could be problematic in many facilities.

Due to the uncertainties associated with building air exchange rates for non-fan ventilated housing systems, only fan ventilated buildings were studied. However, determining the airflow rate in fan ventilated animal facilities is still a challenging task due to the wide variations in airflow rates expected, the wide array of operating static pressures, the wide array of fan configurations, and the harsh environment for any sensing method chosen. For this research project, individual investigators were given the freedom to select and customize airflow rate measurement techniques. This approach cultivated some innovative ideas and approaches to the measurement of animal housing ventilation rate. The single requirement given for each housing system studied however was that all fans and/or all fan stages had to be calibrated on-site at a range of expected operating static pressures using the FANS unit, a portable fan tester, described previously in Heber *et al.* (2002) and Jacobson *et al.*, (2003). The FANS unit consists of an open ended box that is placed in front of (or behind if necessary) a fan. It has a row of five vane anemometers that traverse vertically across the entrance of the fan. This yields a velocity map across the FANS opening that is used to calculate the flow rate entering (or leaving) the fan (Gates *et al.*, 2002; Wheeler *et al.*, 2002). It gives good results when compared simultaneously with the AMCA standard fan test chamber. While this is useful for obtaining fan curves in the field, it is not applicable for continuous measurement of fan performance, especially for multiple fans. In all discussions contained within this paper, all fan airflow calculations were the result of in-field measurements with the FANS unit in which representative barn fans were tested at various operating static pressures and at various variable speed settings, where applicable.

The methods developed for this research project resulted in a wide array of techniques each having their own set of advantages and disadvantages. In all cases, determining the barn's ventilation rate was still a formidable task. The objective of this paper is to describe in general the various airflow rate techniques used by each of the six emission sites monitored for this research project and to present some characteristic results of each method.

MATERIALS AND METHODS

Four swine (Iowa, Minnesota, Illinois, Texas) and two poultry (Indiana, North Carolina) housing systems were studied over a period of about 15 months. For each state, two side-by-side barns were studied. Detailed descriptions of the project can be found in Heber *et al.* (2002) and Jacobson *et al.* (2003). In all cases, the housing systems incorporated 100% fan ventilation, a prerequisite for barn selection. This requirement was imposed for the purpose of isolating emission points and to have controlled locations for estimating mass flow rate. The following discusses the various methods used for determining the mass flow rate of air through fan ventilated swine and poultry housing systems. The methods are grouped into (1) Fan Indication Methods (FIM), (2) Fan Rotation Methods (FRM), and (3) Airspeed Measurement Methods (AMM).

Fan Indication Methods

Fan indication methods were methods designed to determine whether a fan was on or off. With this method, no attempt was made to decipher variable speed fan operation and thus this method was designed and suited for all single-speed fans. Iowa, Texas, North Carolina, and Indiana used primarily FIMs.

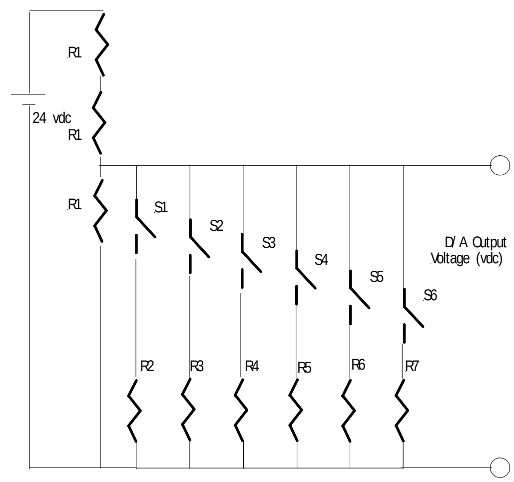
<u>Iowa Fan Arrangement</u>

For the Iowa housing system, a total of eight fans per barn were used arranged as two variable speed 46 cm diameter pit fans, one 61 cm diameter variable speed sidewall fan, one 61 cm diameter variable speed endwall fan, one 91 cm diameter single speed endwall fan, and three 122 cm diameter single speed endwall fans. The endwall fans were arranged to provide hot weather tunnel ventilation. The eight fans were configured into seven ventilation stages. To decipher the seven ventilation stages, six of the eight fans were required to be monitored directly.

Iowa Barn Airflow Rate Method

The Iowa method used limit switches arranged as sails to indicate fan operation. The method used customized sails fitted to an omnidirectional whisker switch (Telemecanique, Inc, Model XCKP106 (18.5 in-oz) or Square D, Inc, Model C54L (6 in-oz)) with a 28 cm long extension arm. The sail switch was used to indicate fan ON/OFF status by allowing fan airflow to activate the switch. However, it was determined early on in the project that airflow rate alone would not activate the switch consistently. To ensure that the sail switch would activate with fan operation, it was determined that a connection between the sail switch and the fan shutter remedied this situation and the final arrangement is shown in Figure 1a. With the configuration shown in Figure 1a, the combination of fan airflow and shutter opening developed adequate activation air for the sail.

The sail switches (six total per barn) were electrically arranged as a digital-to-analog (D/A) converter which resulted in a single voltage output representative of the status of all fans in the barn. This arrangement is given in Figure 1b.



(a) **(b)**

Figure 1. The (a) Iowa sail switch arrangement and (b) circuit arrangement for digital-to-analog output signal indicating barn fan status. Sail switches S1 to S6 attached to six of the eight barn fans to represent one of seven ventilation stages. Resistor values were 1kΩ, 2kΩ, 1kΩ, 0.9kΩ, 0.5kΩ, 0.3kΩ, and 0.15kΩ for resistors R1 to R7, respectively.

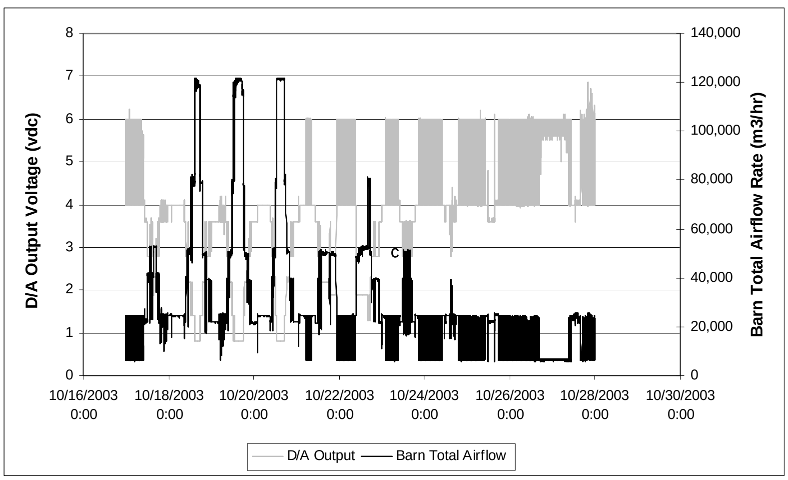
The sail switches were assigned to six of the eight fans and the status of these six fans were used to represent one of seven possible ventilation stages. Sail switches one to six (S1 to S6) were used in combination with resistors R2 to R7. When a switch was activated, current from the 24 vdc power supply circuit would be rerouted causing a change in voltage at the junction shown in Figure 1b. The end result was a status table as shown in Table 1.

Table 1. Voltage indicators for Iowa fan stages

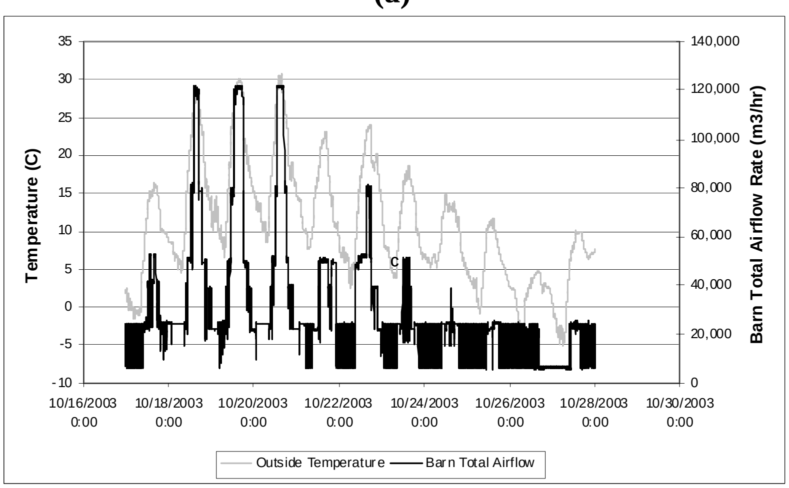
Switch(es) Active	Ventilation Stage	Voltage Output (vdc)
0	0	8
S1	1	6
S1, S2	2	4
S1, S3	3	3.6
S1, S2, S3	4	2.77
S1, S3, S4	5	2.25
S1, S3, S4, S5	6	1.38
S1, S3, S4, S5, S6	7	0.82

Example Iowa Results

The D/A output voltage from the arrangement shown in Figure 1b and the resulting airflow rate results for a 10-day period in October 2003 are given in Figure 2a along with the extreme variations in ambient temperature during this same period (Figure 2b).



(a)



(b)

Figure 2. Example (a) Iowa fan monitoring with the corresponding airflow rates recorded and (b) the airflow rate response as a function of outdoor temperature.

Texas Fan Arrangement

Texas monitored a tunnel ventilated swine finisher that consisted of five total fans per barn. The fans monitored were two 91 cm diameter and three 122 cm diameter fans distributed along the end wall as shown in Figure 3. The barn was ventilated in four stages with the first stage consisting of the two 91 cm diameter fans working continuously between 70% to 100% variable speed. Stages two, three, and four consisted of the two 91 cm diameter fans at 100% with successive 122 cm diameter fans by successive stage.

Figure 3. Texas measurement site showing tunnel exhaust end of barn.

Texas Barn Airflow Rate Method

The Texas site used two FIMs to monitor fan status. A combination of sail switches similar to the Iowa arrangement and coupled with fan relay monitoring was used. Initially, only sail switches were used but errors in fan indication were found due to the inability of the fan airflow rate to deflect the sail. To remedy this situation, 110VAC relays were added to monitor power inputs to each fan as a supplement to sail switch data. Sail switch failures were found during those times with minimal airflow rates caused either by variable speed action or excessive operating static pressure. As with all other sites monitored, the FANS unit described previously was used to generate all fan airflow versus static pressure calibration curves. The Texas example is shown in Figure 4.

Figure 4. Fan calibration process at the Texas site.

Example Texas Results

Figure 5 shows the ventilation rate measurements recorded and the barn temperatures achieved for the first week in July 2003. Clearly, the ventilation rate method captured the expected diurnal ventilation rate changes. To give one an idea of the errors associated with using test report data only, the maximum airflow rate delivery for the five fans in the Texas set-up would predict a maximum airflow rate capacity of about 37 m^3/s. In actuality the maximum was about 28 m^3/s. Therefore, the barn's maximum ventilation rate was about 76 percent of the design values used from test report data.

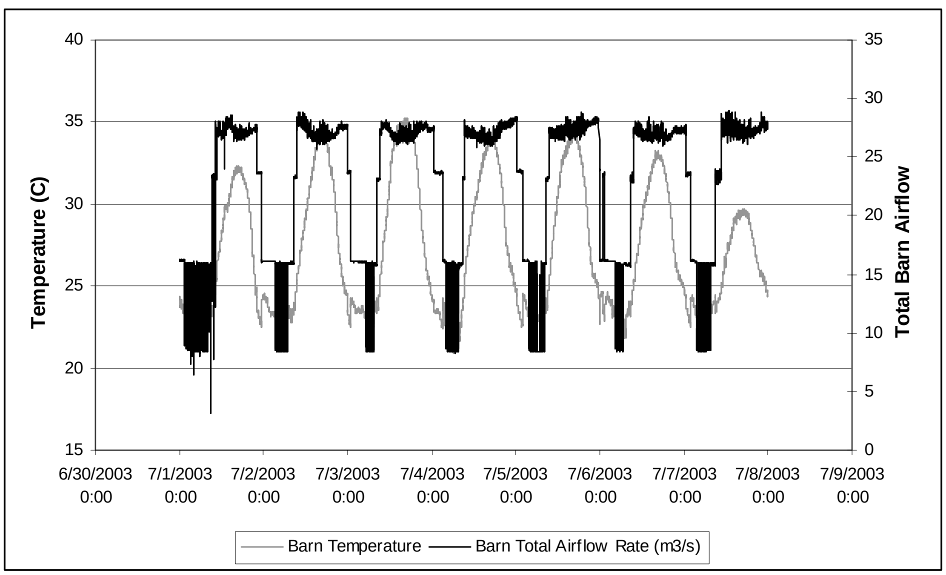
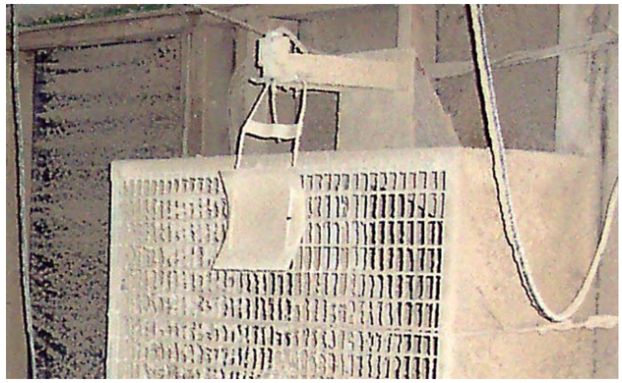


Figure 5. Example Texas results for July 2003. Airflow in m^3/s.

North Carolina Fan Arrangement

North Carolina monitored a broiler facility that consisted of ten total fans per barn. The sidewall fans monitored consisted of one single speed 91 cm diameter fan and nine single speed 122 cm diameter fans. The FIM used in North Carolina consisted of sail switch mechanisms as shown in Figure 6a. This initial design proved too fragile and unreliable, as the sail would twist and give false readings. An improved model with a larger sail, rigid frame and an axle was implemented (Figure 6b) which proved to be more robust and responsive.



(a) **(b)**

Figure 6. Initial sail switch arrangement used in North Carolina.

North Carolina Barn Airflow Rate Method

Broiler house ventilation was provided by a single 91 cm direct drive fan and nine 122 cm belt driven fans. The belt driven fans had fixed centers and segmented belts; belt tension could only be adjusted by removing segments and shortening the belts. This was a cumbersome and time consuming process. Spot RPM measurements indicated that at any given time at least half the belt drive fans were slipping (some by as much as 20%). Monitoring the decay in belt driven fan performance requires real time RPM counters and data acquisition. Lacking this capability our group decided to tighten all the belts in house two and leave those in house three to the farmers care. Subsequent FANS analyzer work indicated that house three had greatly reduced total air flow capabilities. Healthy flocks could be raised in spite of this condition because the ventilation system was over designed. To compensate for the reduced air flow of its fans the controller in house three would activate more fans than the controller in house two; during hot weather the ratio was approximately 4/3. Under the assumption that the ventilation controllers in each house would adjust to provide similar flow rates the flow rates from house two (tightened fans) were used to calculate the emission rates for both houses.

Back drafting thru broken and dust laden fan shutters was another source of concern and discharge rate error. Sail switches are incapable of detecting this leakage. In tunnel ventilated broiler houses heavy dust loads regularly cause shutters to stick open. It is recommended that future air quality work at broiler facilities implement the use of RPM counters to detect individual fan flow rates.

Indiana Fan Arrangement

Indiana monitored a layer facility that consisted of seventy-five (75) 122-cm diameter belt driven exhaust fans on each barn. Ventilation air was introduced to the caged layer region from the attic through temperature-adjusted baffled ceiling air inlets over each row of cages. The 75 fans were distributed in the pit area of the high-rise layer with 37 fans distributed along the west sidewall and 38 distributed along the east sidewall. The fans were spaced 3.7 m apart in groups and the groups were 7.3 m apart. Each barn utilized nine ventilation stages as shown in Table 2.

Table 2. Fan numbers and ventilation stages for the Indiana high-rise caged layer.

Stage	Number	ID of fans for each stage
1	5 (continuous)	1,20,37,47,67
2	5+5=10	10,29,39,57,75
3	10+8=18	5,15,24,33,43,52,62,71
4	18+8=26	6,16,25,34,44,53,63,72
5	26+8=34	4,14,23,32,42,51,61,70
6	34+8=42	7,17,26,35,45,54,64,73
7	42+14=56	3,9,12,18,22,28,31,38,40,49,55,59,65,69
8	56+19=75	2,8,11,13,19,21,27,30,36,41,46,48,50,56,58,60,66,68,74
9	75-19=56	Evaporative pads on, stage 8 fans off

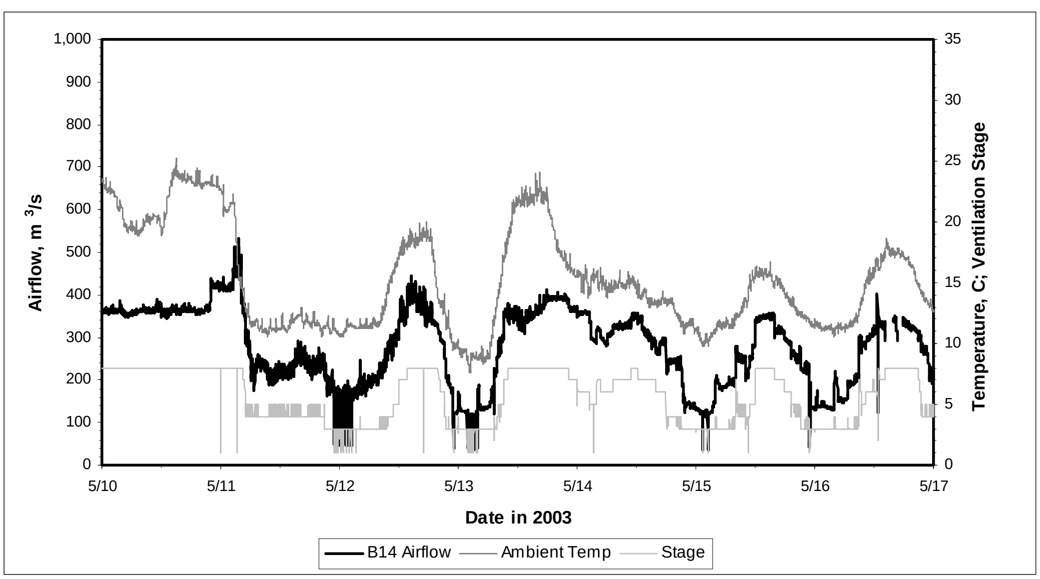
Indiana Barn Airflow Rate Method

Building static pressure was measured between the center of the manure pit and both the north and south sides of the building. The outside port was located against the outside wall directly between two fans. These pressures were different with northerly and southerly winds.

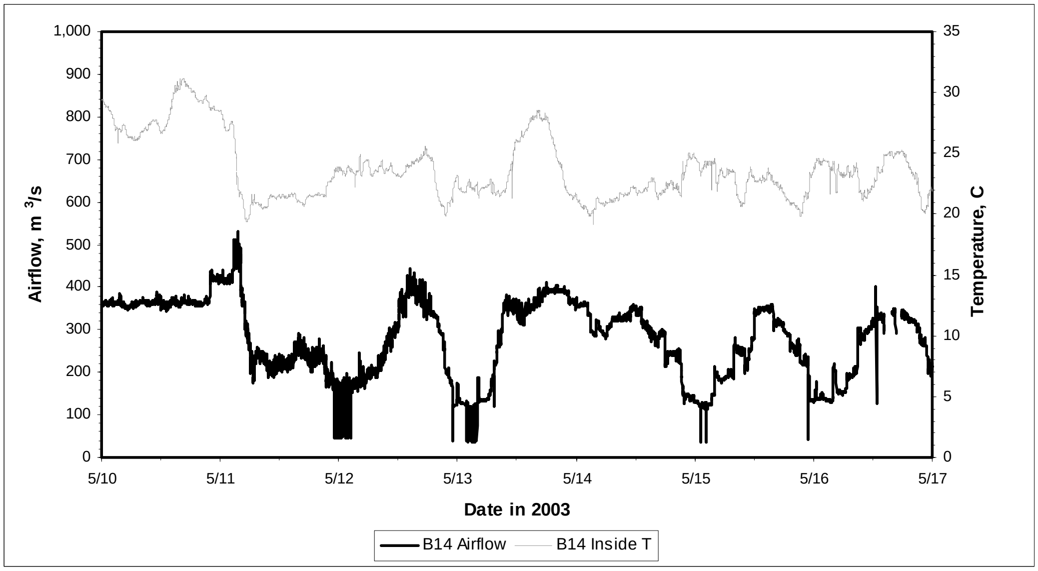
Fan operation was monitored by using unused contacts of fan motor relays in 5-VDC circuits in conjunction with digital inputs of the data acquisition system. The ventilation stage operation was monitored by sensing at least two fans in parallel per stage. Each fan was tested with the FANS analyzer to determine the fan degradation. A revised fan curve was developed for each fan.

Example Indiana Results

Figure 7 shows a 7-day response of the Indiana set-up in May 2003. The contact relay response, indicating fan ventilation stage, is given in Figure 7a along with the outside temperature. The fan ventilation stage indicator was then used to determine the operating fans, and based on FANS calibration and the current operating static pressure, the barn's total airflow rate could be determined as shown in Figure 7a. The resulting inside temperature control at one location in the caged area of the high-rise is given in Figure 7b.



(a)



(b)

Figure 7. Example results from one of two Indiana high-rise layer facilities monitored showing (a) ventilation stage monitoring and subsequent airflow calculated as affected by ambient temperature changes and (b) temperature response inside the barn at one location.

Fan Rotational Methods

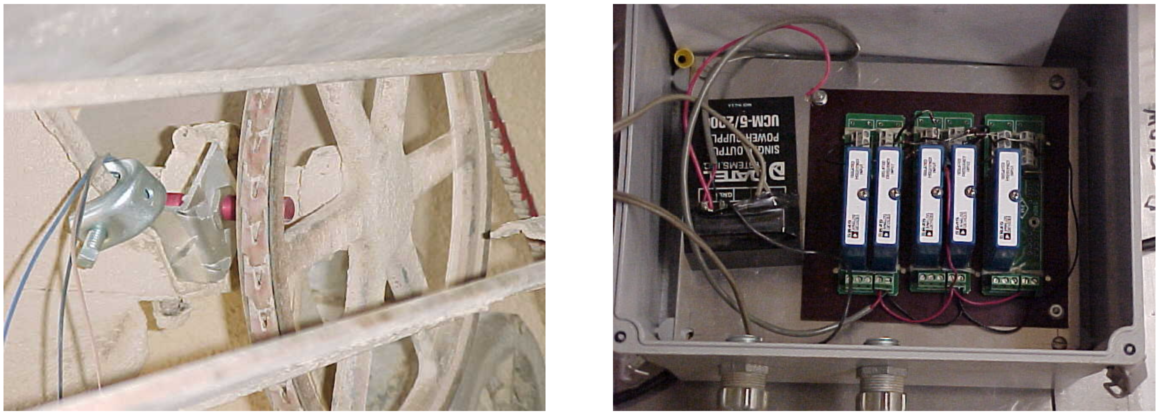
Fan Rotational Methods (FRM) were those techniques used to detect fan operational status and simultaneously assess the variable speed nature of fans by direct measurement of fan RPM. Minnesota used this method exclusively and Iowa used this method for the two variable speed fan banks in their set-up.

Minnesota Fan Arrangement

Minnesota monitored a swine gestation and breeding facility. The fans monitored for RPM consisted of five temperature controlled 120 cm diameter belt driven fans per barn. Each barn also had a 91 cm diameter variable-speed fan that ran continuously and thus did not need to be monitored. In the breeding barn, each fan was on a separate thermostat control so that as the barn temperature increased, an additional fan would operate. The gestation barn had an integrated heating/ventilation/cool cell controller. For this barn, the 120 cm fans were staged in pairs with a differential temperature setting of 0.5°C.

Minnesota Barn Airflow Rate Method

Minnesota used magnetic pickup sensors (Cherry model GS100501) arranged as shown in Figure 8a to assess simultaneously fan status and rotational speed. Each magnetic sensor was mounted to detect the motion of the spokes on the cast iron fan pulley. The magnetic sensor produced a frequency signal which was then converted to a DC voltage signal by the frequency-to-voltage converter shown in Figure 8b. The measured RPM levels for each fan as a function of various operating static pressures were calibrated using the FANS unit and subsequent calibration curves were developed. The 120 cm diameter fans had segmented belts that were susceptible to slippage and reduced airflow delivery so monitoring of the rpm was possible along with the selection of the closest calibration curve.

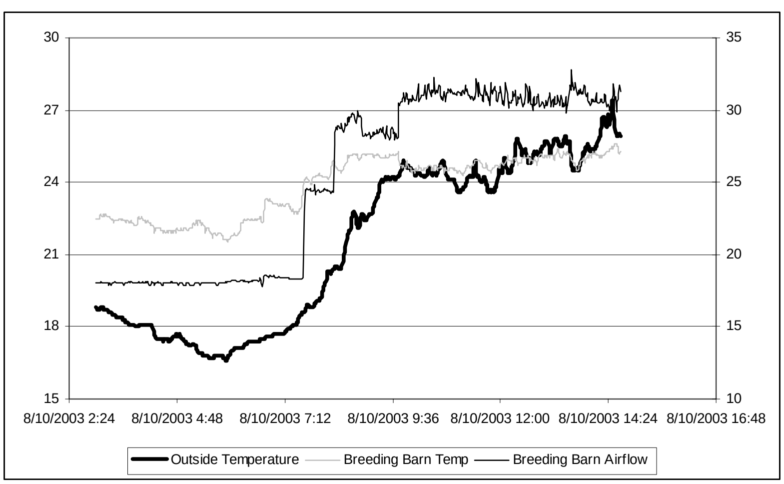


(a) (b)

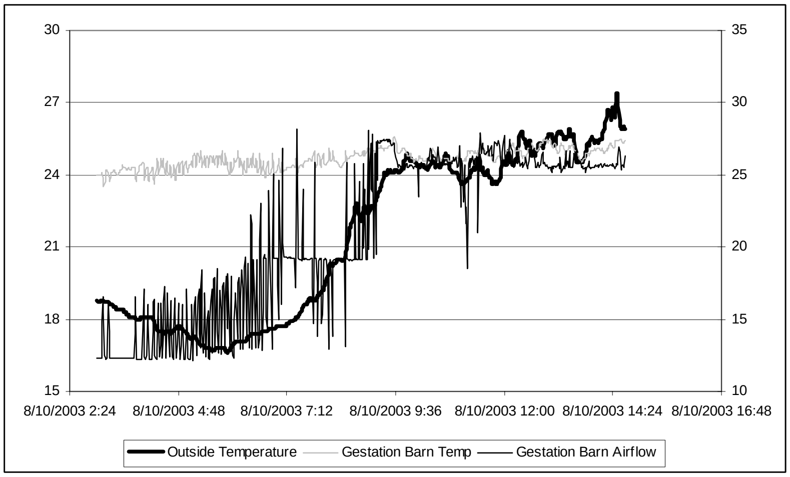
Figure 8. Installation of (a) RPM sensors and (b) signal conditioning bank required for RPM monitoring.

<u>Example Minnesota Results</u>

Figure 9 summarizes the Minnesota airflow rate measurement method for one day for the breeding barn monitored (Figure 9a) and the gestation barn monitored (Figure 9b). In the gestation barn, the second stage was set by the operators of the barn to control two of the 120 cm fans with a tight 0.5^{o}C temperature differential. Such operation resulted in rapid cycling of the second stage fans, sometimes only running for less than two minutes and off for less than two minutes. The “noise” in the early morning shown in Figure 9b was typical of the resulting airflow during the conditions that required more ventilation than what the 91 cm diameter continuous running ventilation fan could provide. When ambient temperature increased requiring additional ventilation, the operation of the temperature controlled fans was much more constant. The RPM sensors were able to easily record this rapid cycling and thus produce input to calculate the airflow of the barn on a continuous basis.



(a)



(b)

Figure 9. Example airflow rate measurements for the (a) breeding barn and (b) gestation barn for August 10 2003 as a function outside temperature and resulting inside barn temperature. For both figures, the left axis is temperature, ^{0}C and the right axis is airflow rate, m^3/s

Airspeed Measurement Methods

Airspeed Measurement Methods (AMM) were those techniques developed to simultaneously detect fan operational status and assess the variable speed nature of fans by measuring a representative airspeed through the flow net of the fan. Heber (2003) introduced this method and Illinois used it for all monitored fans at their site.

Illinois Fan Arrangement

The Illinois site monitored was a swine farrowing facility consisting of sidewall fans that varied between 61 and 122 cm in diameter.

Illinois Barn Airflow Rate Method

The Illinois AMM used a single propeller (RM Young Model 27106RS with Model 08234 propeller) positioned at either the intake (Figure 10) or exhaust side of each fan and the rotational speed of this propeller was calibrated against the fan airflow rate as a function of operating static pressure.

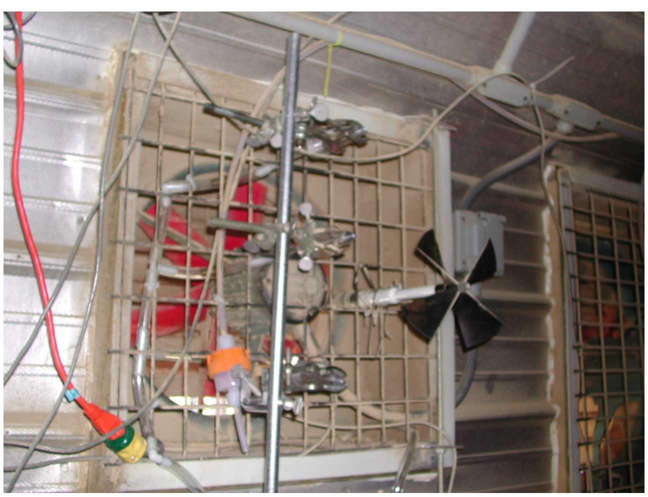


Figure 10. Propeller anemometer positioned at the intake side of a 61 cm diameter fan monitored in the Illinois set-up.

The propeller anemometer consisted of an 18 cm diameter vane attached to a sealed bearing DC generator that produced a 0-1 VDC output proportional to rotational speed. The anemometer was placed at the inlet side of the fan for all 61 and 76 cm diameter fans and at the exhaust side for all 91 cm diameter fans. The exact location of the anemometer in front of the fan depended on the size of the fan and the airflow pattern. For the two smaller fans, the anemometer was positioned as close to the fan as possible and faced upstream. With the larger fan the anemometer was placed just inside the cage of the cone facing into the exhaust stream.

To test the anemometers ability to measure the flow rate of agricultural fans the AMCA standard (ANSI/AMCA, 1999) test facility at the University of Illinois Urbana-Champaign was used. This facility is the industry standard test site for agricultural fans. It has the capacity to test all typical fans sizes at static pressures ranging from zero to 5 kPa, well above any typical operating pressures. Several tests were conducted to test propeller position relative to the fans flow net and to calibrate propeller output with actual fan airflow. Details of this work can be found in McClure *et al.* (2004).

Figure 11 shows the propeller anemometer output voltage as a function of fan air flow for the 61 cm fan tested with the propeller positioned at the four compass points about the intake side of the fan.

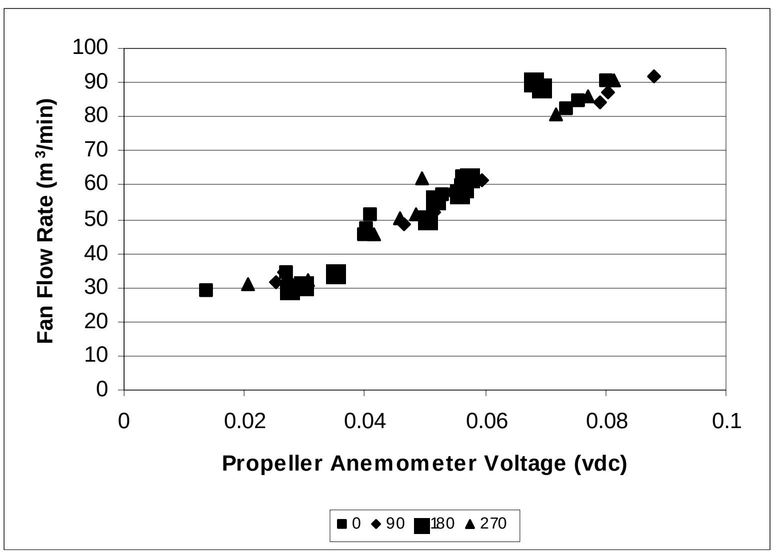
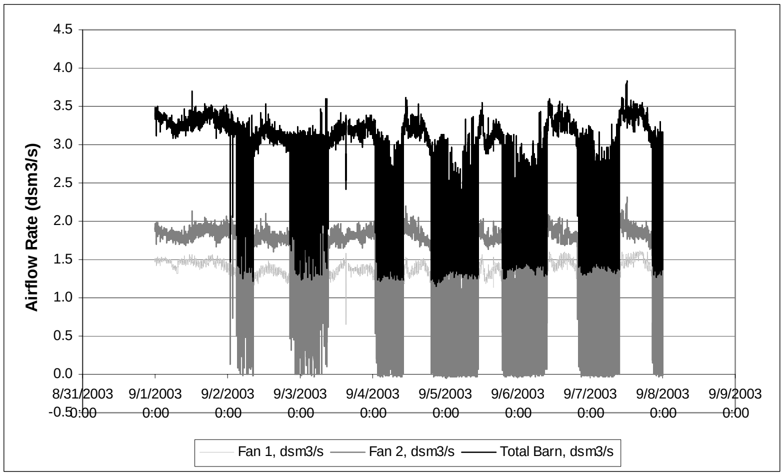


Figure 11. Example propeller anemometer results as a function of fan airflow rate for a 61 cm diameter fan used in the Illinois set-up. The designations 0, 90, 180, and 270 correspond to the four compass point locations where the propeller anemometer was tested.

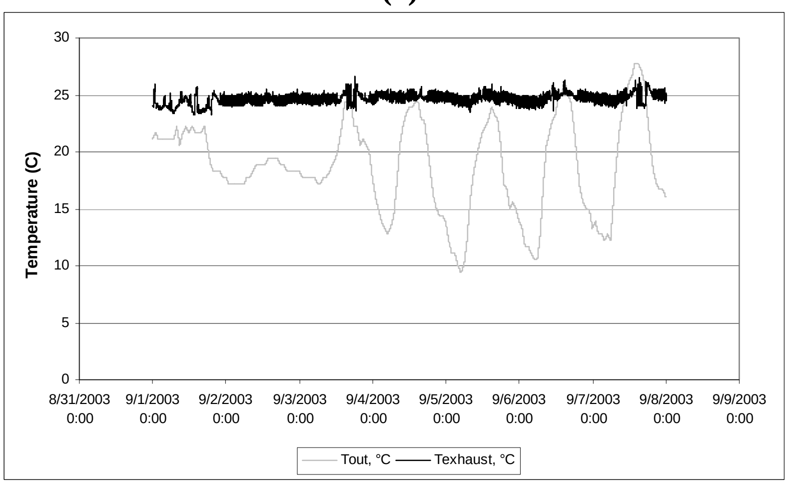
The anemometer tested in this study showed good linearity with the fan flow rate for all of the fans tested. Based on this analysis, it is best to calibrate the anemometer for the specific fan and location of interest. As expected the anemometer response is fairly sensitive to location relative to the fan as well as the arrangement of the building in which it is installed. It appears that the anemometer will perform well as long as the proper calibration is done. It does not appear that a general calibration curve for a certain fan curve can be offered with great accuracy. For application where high accuracy is not necessary then general curves could be developed in the lab for use in the field.

Example Illinois Results

Figure 12 gives an example 7-day result for one of the Illinois farrowing rooms studied showing the individual fan airflow rate delivery (Figure 12a) and the resulting inside climate temperature as a function of the varying outside temperature (Figure 12b).



(a)



(b)

Figure 12. Example (a) individual fan and total barn airflow rate and (b) the resulting inside and outside temperatures for a 7-day period in September 2003.

DISCUSSION

The emission study that formed the basis for the work described in this paper required the assessment of airflow rate delivery for each barn studied. Flexibility was given to each research team to develop methods that best suited their research site. Using this approach fostered a climate of innovation that resulted in the techniques described within this paper. Each of the methods discussed has advantages and disadvantages and Table 3 categorizes these.

Table 3. Summary of fan airflow rate measurement methods used with advantages and disadvantages of each based on experiences gained from this research project.

Category	Method	Advantages	Disadvantages
FIM	Sail switch	-simple -inexpensive (approx $20/fan) -many fans can be configured into one analog output (as with any digital signal)	-requires attachment to a shutter -susceptible to mechanical failure -sensitive to low airflow events caused by high static pressure or variable speed action -sensitive to dust build-up
	Contact relays	-inexpensive (approx $2/fan) if dry contact available on existing relay -configurable into one analog output -can sense entire stage with one signal.	-sensing a stage of multiple fans assumes all fans are operating -requires fan wiring intervention -if no dry contact, then $50-$100/fan needed for 240VAC relays to sense fan voltage -susceptible to false positives (burnt motor, belt off, impeller off, disengaged fan motor). -susceptible to false negative (failed contact)
FRM	RPM sensor	-fan status and fan rotation data in one signal -can be used to assess slippage	-susceptible to dust build-up -requires pulse input counters or supplemental signal conditioning -costly at about $70/fan
AMM	Small propeller anemometer (SPA)	-fan status and fan variable flow in one -output directly readable by most DAC systems -no excitation voltage required -does not require static pressure knowledge once calibrated against a fan/SP combination -not susceptible to false positives. -cut-in air speed an issue with variable speed fans.	-mounting can be a challenge. -expensive per fan cost (costs $450/fan. -sensitive to dust (must be cleaned regularly). -sensitive to placement within the fans airstream.

CONCLUSIONS

A multi-state research project was conducted in which the emission of hydrogen sulfide, ammonia, PM10, and odor were measured. A critical variable in all emission work is the ability to accurately measure the mass flow rate through the housing unit. This research project used a wide variety of methods, all with the intention of measuring building mass flow rate as accurately as possible. Three general methods were incorporated and they fall under one of three categories identified as Fan Indicator Methods, Fan Rotational Methods, and Airspeed Measurement Methods. Each method has advantages and disadvantages and the best method to use for a site depends on several factors. It is recommended though that a combination of methods be used. For example, a FIM combined with a FRM would provide one of two methods that yield at the very least an indication of fan status. This recommendation would help in data preservation as sensing methods will fail at times throughout long-term emission studies.

ACKNOWLEDGEMENTS

The authors would like to thank the United States Department of Agriculture for funding this research project under the USDA-IFAFS research and demonstration program. We dedicate this work to the memory of Dr. Bob Bottcher, our colleague and friend.

REFERENCES

ANSI/AMCA Standard 210-99. 1999. Laboratory Methods Of Testing Fans for Aerodynamic Performance Rating ANSI/AMCA Standard 210-99, 1999.

Berckmans, D., P. Vandenbroeck, V. Goedseels. 1991. Sensor for continuous measurement of the ventilation rate in livestock buildings. Indoor Air 3, 323-336.

Demmers, T.G.M, L.R. Burgess, V.R. Phillips, J.A Clark, C.M. Wathes. 2000. Assessment of techniques for measuring the ventilation rate, using an experimental building section. J. Agric. Engng. Res. 76, 71-81.

Gates, R.S., J.D. Simmons, K.D. Casey, T. Greis, H. Xin, E.F. Wheeler, C. King, J. Barnett. 2002. Fan assessment numeration system (FANS) design and calibration specifications. 2002 ASAE Annual International Meeting, 28-31 July. Chicago, IL.

Heber, A.J., J.Q. Ni, T.T. Lim, P.C. Tao, A.M. Millmier, L.D. Jacobson, R.E. Nicolai, J.A. Koziel, S.J. Hoff, Y. Zhang, and D.B. Beasley. 2002. Quality assured measurements of animal building emissions: Part 1. Gas concentrations. *Symposium on Air Quality Measurement Methods and Technology*, San Fransisco, CA. November 13-25, Air and Waste Management Association. Pittsburg, PA.

Heber, A.J. 2003. Air emission measurements at livestock houses: a hide-and-seek challenge to find the numbers. Resource 10(4):7-8.

Jacobson, L.D., A.J. Heber, Y. Zhang, J. Sweeten, J. Koziel, S.J. Hoff, D.S. Bundy, D.B. Beasley, and G.R. Baughman. 2003. Air pollutant emissions from confined animal buildings in the U.S.. *In: Proceedings of the International Symposium on Gaseous and Odour Emissions from Animal Production Facilities.* Horsens, Denmark. June 1-4, 2003. pp 194-202.

Maghirang, R.G., Y. Liu, D.S. Chung. 1998. Evaluation of a freely rotating impeller to measure fan airflow rates in livestock buildings. Transactions of the ASAE, 41(3), 819-824.

McClure, J.W., S. Jerez, and Y. Zhang. 2004. Continuous Measurement of Confined Animal Housing Ventilation Rates for Determining Pollutant Emissions. Proceedings of the 97th Conference on Air & Waste Management Association. Indianapoils, IN, June 21-25, 2004.

Wheeler, E.F., R.S. Gates, H. Xin, J.S. Zajackowski, P.A. Topper, K.D. Casey. 2002. Field estimation of ventilation capacity using FANS. 2002 ASAE Annual International Meeting, 28-31 July. Chicago, IL.