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Temporal Variation In Swine Confinement Indoor Air Quality

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ABSTRACT

Human health hazards can exist in swine confinement buildings due to poor indoor air quality especially as a result of high respirable dust and ammonia concentrations. The purpose of this study was to access the temporal variability of airborne dust and ammonia levels in a working farrowing facility over both a daily and seasonal basis. An ammonia sensor, aerosol photometer, internal relative humidity sensor, and datalogger containing an internal temperature sensor were mounted on a board suspended just above the worker breathing zone in the center of a room in the facility. Sensor readings were taken once every 4 minutes continuously between successive room washings, which occurred on a 3-week basis. Sensor readings, standard methods for the measurement of total and respirable dust concentrations, aerosol size distribution, and ammonia concentrations were taken once per week in addition to temperature and relative humidity measurements using a thermometer and sling psychrometer, respectively. Samples were taken between September 1999 and September 2000. The continuous readings of both dust and ammonia concentrations revealed a pattern that was inversely related to internal temperature and the related ventilation rate. This pattern was most apparent during weeks exhibiting large variations in daily external temperatures. As expected, seasonal differences demonstrated an increase in contaminant concentrations during the cold weather months. However, average dust concentrations were very low (<0.1 mg/m^3) throughout the year. Likewise, ammonia concentrations averaged 3.6 ppm.

KEYWORDS. Animal housing, air quality, real-time sensors

INTRODUCTION

A large increase in the number of intensive hog production facilities has been evident in recent years. Many studies have identified these "confinement" buildings as hazardous work places (Donham et al.1989; Donham 1990; Heedrick et al. 1991; Barber et al. 1991; Larson et al. 1994). These facilities are operated with a high animal density in buildings that are generally enclosed during the winter months to minimize heating costs. The combination of increased stocking density and low ventilation rates has contributed to poor indoor air quality (IAQ) within confinements that can be hazardous to workers' health (Takai 1997). Although the gaseous portion of these aerial pollutants may be hazardous to health, particularly the high ammonia concentrations (Donham et al. 1988), equal concern has been given to the high particulate portion. Microscopic analysis of dust in pig farms showed that feed and feces were the major constituents of dust in confinements (Donham et al. 1986). The concentration of airborne dust in swine confinements may be affected by increased animal activities, low ventilation rates, feeding practices, bedding materials, flooring type, and dung and slurry handling (Preller et al. 1995; Takai et al. 1995). A study conducted to determine the amount of inhalable dust typically found in swine confinements in the Netherlands reported values ranging from 0.3 to 26.6 mg/m^3 (Preller et al. 1995) and a similar study performed in Iowa reported averages of 0.53 and 6.25 mg/m^3 for total and respirable (< 4 µm) dust respectively (Donham et al. 1986).

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Many swine confinement buildings are built with manure storage structures below the slatted floors of the animal pens. Manure is typically stored for 3 to 9 months in a liquid form (10% solids) prior to removal for land application (Donham et al. 1988). In these pits, the manure undergoes anaerobic digestion, during which up to 40 different gases and vapors can be generated. Of these, methane (CH_4), hydrogen sulfide (H_2S), ammonia (NH_3), and carbon dioxide (CO_2) are the major compounds. Studies have shown that health problems associated with exposure to H_2S and NH_3 in swine confinements include irritation of the eyes, mucous membranes, and respiratory tract (Donham and Gustafson 1982). The production of gases by manure stored in a confinement varies in relation to the age of the manure after cleaning, time of year, and animal age. Ammonia measurements in confinement buildings taken during one study varied between 13 and 76 ppm. However, only a portion of the NH_3 was determined to originate from manure and the rest from urine and manure that accumulates on top of the slatted flooring (Donham et al. 1988).

Total dust and ammonia levels in the range of their respective threshold limit values (TLVs, ACGIH 2000) have been shown to be significant contributors to respiratory disease in swine confinement workers (Donham et al. 1989; Robertson 1993). Therefore, more stringent TLVs for application in swine confinements of 0.23 mg/m^3 for respirable dust, 2.4 mg/m^3 for total dust, and 7 ppm of ammonia have been proposed (Donham et al. 1989). It has been shown that improved air quality resulted in improved human respiratory responses (Zhang et al. 1997). However, in terms of animal health, studies have shown that little economic benefit, as determined by weight gain relative to feed consumption, are expected when current levels of airborne dusts in swine confinements are reduced (Takai et al. 1995; Klooster 1993). Conversely, some reduction (12%) in the growth rates of young pigs was found when exposed to a concentration of 50 ppm of ammonia (Drummond 1980).

The research presented here was undertaken as part of a larger research agenda, which includes an analysis of the effect of ventilation rates on confinement IAQ. This study had as its primary goal the development of an understanding of the temporal variation in airborne dust and gaseous ammonia concentrations within a working confinement. A farrowing facility was chosen as the study site because the facility is completely reliant on mechanical ventilation for all air moved through the building. A complimentary goal was to evaluate the accuracy of real-time sensors in the harsh environment of a confinement over a year-long period by comparison with standardized sampling methods.

METHODS

Two air contaminants, ammonia and particulate matter, were continuously monitored for week-long periods between September 1999 and September 2000 in a farrowing facility associated with the Swine Education Center of Kirkwood Community College of Cedar Rapids, Iowa. One room of the facility was used as part of this research. The room measured 7 m by 9 m and contained two rows of 5 pens each with a central isle separating the two rows. Floor grating separated the room area from the waste pit area. One variable-speed fan was mounted on the far wall to pull air through the room and down into the pit area before exhausting. Two fans were also mounted on the center of the outside wall to increase the air exchange rate as needed to decrease room temperature during warm days.

Ammonia was measured using a direct-reading instrument (Ammonia-Stat, Industrial Scientific Corporation, Oakdale, PA) and particulate matter was measured using an aerosol photometer (Handheld Aerosol Monitor, PPM Inc., Knoxville, TN). Two environmental parameters, temperature and relative humidity, were also monitored inside the study area. A current-transmitting meter was purchased to monitor relative humidity (HMW60U, Vaisala, Helsinki, Finland) and temperature was recorded with a sensor associated with the datalogger used to record readings (Smart Reader Plus 7, ACR Systems Inc., Surrey, British Columbia). The sensors and datalogger were mounted to a board and suspended in the center of a room in the swine confinement, just above the worker breathing zone. On a weekly basis, the photometer was cleaned by spraying the "view volume" of the sensor with filtered, compressed air. Each room of the farrowing facility was occupied on an approximately 3-week basis between which were 5 to 7 days for cleaning. Therefore, the readings taken did not represent a continuous recording throughout the year-long sample period.

The particular datalogger used during this study was only capable of retrieving and storing a voltage signal from a sensor in the range of 0 to 5 V. The aerosol photometer produced an output voltage of 0 to 2 V proportional to 0 to 20 mg/m^3. Therefore, an operational amplifier was used to increase the output by a factor of 2.5 to take advantage of the full range of the datalogger. Furthermore, both the relative humidity sensor and the ammonia sensor produced a current signal of 4 to 20 mA proportional to the full range of each instrument; 0 to 100% and 0 to 100 ppm, respectively. Therefore, 250Ω resistors were used to produce a 1-V and 5-V signal when the sensors transmitted a 4-mA and 20-mA signal, respectively. The voltage readings from the datalogger were taken once every 4 minutes and downloaded once during each week of sampling. These readings were then imported into a spreadsheet for conversion to the physical values represented by each voltage reading. For example, the equation relating voltage to ammonia concentrations (ppm) was:

$$ppm = 25V - 25$$

On the same day that the datalogger was downloaded, 8-hour samples were taken for particulate matter and ammonia. A measure of "total dust" was taken as per NIOSH Method 0500 with the exception of using an "open-face", rather than "closed-face", filter cassette . Furthermore, a cyclone (BGI Inc., Waltham, MA) was used to measure respirable dust, and a 5-stage cascade impactor (Series 290, Anderson Inc., Smyrna GA) was used to determine the particulate size distribution. Results from this instrument are expressed in terms of the geometric mean and geometric standard deviation of the aerosol size distribution under the assumption that the aerosol has a lognormal distribution (Cooper, 1993). Sampling was carried out using a large pump attached to a long piece of vinyl tubing draped over the sampling board. The tube was branched out using Y connectors, which in turn were connected to flow restrictors (critical orifices) that were calibrated to a desired flow rate of 2.0 L/min for total dust and cascade impactor sampling and 4.0 L/min for respirable dust sampling.

Ammonia was sampled using a sulfuric-acid-treated silica gel sorbent tube (SKC Inc., Eighty Four, PA) as per NIOSH Method 6016. A critical orifice providing a flow rate of 0.30 L/min was used to draw air through the sorbent tube. The silica gel was removed from each tube approximately once every two months after storage in a refrigerator, desorbed in distilled water, and injected into an ion chromatograph for analysis relative to prepared standards.

Relative humidity and temperature measurements were taken using a sling psychrometer and associated dry-bulb thermometer, respectively. These measurements were compared to measurements taken from the datalogger at the same time as those taken with the psychrometer. This comparison was made at both the beginning and end of each sample period on a weekly basis.

RESULTS

The relative accuracy of each sensor was a primary consideration associated with this study. Once the relationship between sensor readings and measurements taken when using standardized methods was established, the time-varying nature of the readings was analyzed. Therefore, results are presented in a similar order that first indicates the accuracy of each instrument and then demonstrates the daily and seasonal variations in readings recorded in the confinement room.

Sensor Accuracy

The relationships between the various sensors used during this study and the established sampling methods for each are given in Table 1. The following information is given in Table 1 for each comparison: the sample size (n), the range of measurement values; a linear equation and associated r^2 value relating the standardized measurement value (X) to the corresponding sensor value (Y); and the lowest and highest 95% confidence value associated with the regression line to give an indication of the accuracy of the instrument. For example, a plot showing the relationship between humidity measurements made with the sensor in relation to those made with a sling psychrometer is given in Figure 1. For that relationship, the 95% confidence interval about the central value of 65% RH is +/- 4.6%, which expands to +/- 11% near the extreme values of 40% and 100%.

Table 1: Sensor measurements relative to measurements made with standardized methods.

Comparison*	n	Range	Equation	r^2	95% CI
Humidity	66	40 – 100%	Y = 0.90X – 18.46	0.53	4.6 to 11%
Temperature	65	15 - 30°C	Y = 0.88X + 4.50	0.73	0.83 to 1.00°C
Total Dust	18	0.01 – 0.30 mg/m^3	Y = 0.291X + 0.191	0.02	0.093 to 0.260
Respirable Dust	18	0.001 – 0.054 mg/m^3	Y = 0.227X – 0.456	0.01	0.093 to 0.300
Ammonia	17	0.6 – 14.0 ppm	Y = 0.193X + 6.83	0.04	1.94 to 5.00

* Comparisons between sensor reading (Y) and standardized measurement (X)

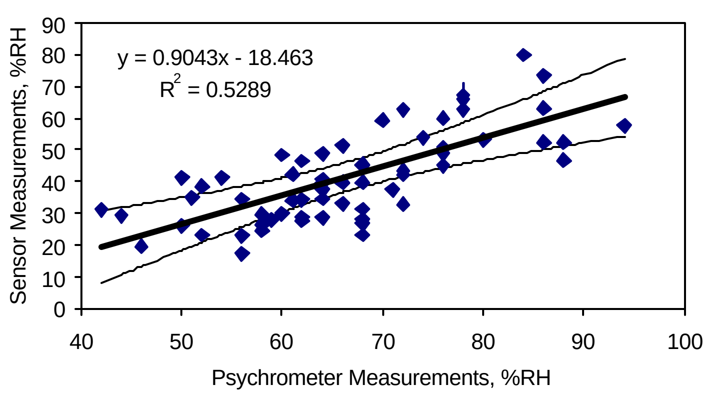

Figure 1. Linear regression comparing sling psychrometer readings with relative humidity sensor measurements.

An analysis to indicate whether sensor response changed over the course of the sample period was also performed by comparing the ratios of sensor measurements to standardized methods over the yearlong sample period. Linear regressions comparing these ratios to days after the start of the sampling period were computed and an analysis performed to determine whether the slope was significantly different from 0. Results from that analysis demonstrated that the temperature sensor and aerosol photometer response remained relatively stable throughout the sample period. However, photometer readings often increased during the course of a sample period and between cleanings (see Figure 3). The slopes for both the humidity and ammonia ratios were significantly negative. Using the resulting regression lines as a basis of comparison, the humidity sensor readings dropped to 63% of the readings taken at the beginning of the study. Likewise, the ammonia readings dropped to 30% of initial readings, however much of that decrease occurred after the first three months of use. The average ratio of the first 4 readings compared with that of the last 4 readings indicated a drop to 40% of the initial readings.

Daily Variations

In general, daily variations in both environmental and contaminant measurements varied more during warm weather than cold weather. As shown in Figure 2, diurnal variations in dust concentration were evident over several days in May when external temperatures varied from 8 to 20°C. Fluctuations in external temperature caused related changes in internal temperature and the air flow rate through the confinement room as more air was required to minimize overheating the area. Therefore, oscillations in dust concentration occurred where higher concentrations were evident during the night when temperatures were coolest and the air exchange rate the lowest. This pattern is contrasted with that evident during cold periods when only the pit fan was operating at a low speed. During those times, there was little difference between night and day concentrations as the fan speed remained consistently low throughout that time period (Figure 3).

Similar patterns were also evident in plots made of ammonia concentrations over time except that the relationship between temperature and concentration was not as well defined. As shown in Figure 4, ammonia concentrations increased with low temperatures and, hence, low air exchange rate. However, a secondary peak occurred as temperatures increased. This may be a consequence of a resulting increase in flow rate and greater mixing between the room and pit areas causing a subsequent increase in ammonia concentrations. This phenomenon was not apparent in all warm-weather recordings however.

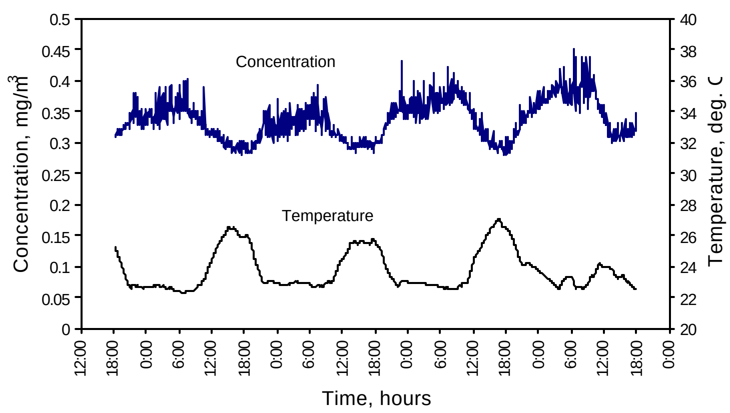

Figure 2. Dust concentrations relative to internal temperature during warm weather period.

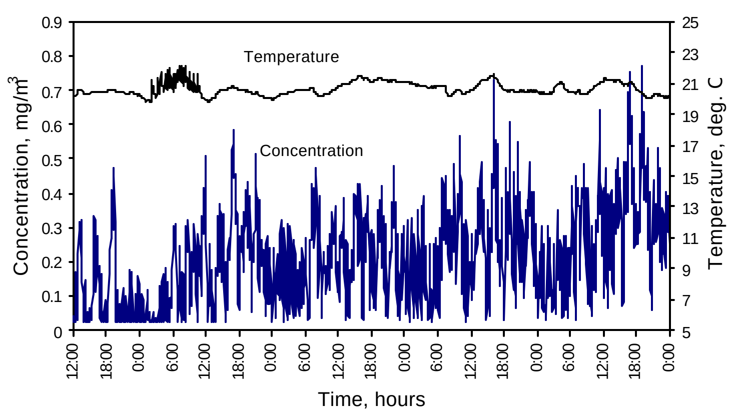

Figure 3. Dust concentrations relative to internal temperature during cold weather period.

Seasonal Variation

The geometric means of all standardized samples taken during the project period were computed (Table 2). As shown in Table 2, the dust levels in the confinement were very low relative to the threshold limit values of 10 mg/m^3 and 3 mg/m^3 for total and respirable dust respectively. The measured levels changed with the seasons with a doubling of the concentration between summer (June, July, and August) and winter (December, January, February). Ammonia concentrations, however, were greatest in the fall (September, October, December) with values four times that of spring (March, April, May) and summer. The geometric mean diameters measured with the cascade impactor remained relatively constant throughout the year at levels between 11 and 14 µm.

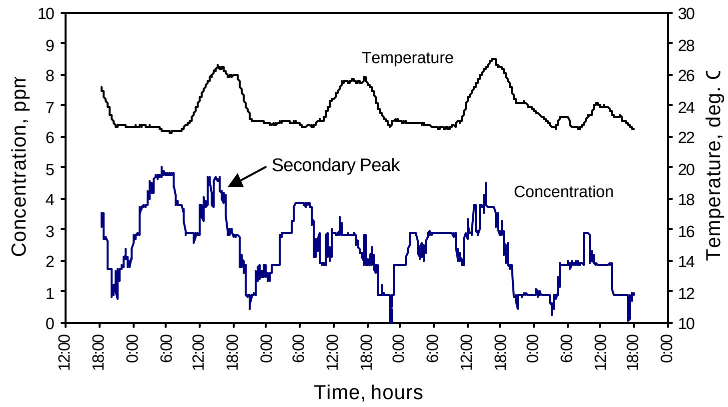

Figure 4. Ammonia concentrations relative to internal temperature during warm weather period.

Table 2. Seasonal variation in contaminant levels.

	Total Dust mg/m^3	Respirable Dust mg/m^3	Ammonia ppm	Diameter Geo. Mean µm
Fall	0.050	0.013	8.0	13.8
Winter	0.089	0.020	5.6	11.2
Spring	0.066	0.017	2.2	12.8
Summer	0.038	0.009	2.0	10.9

DISCUSSION

During this research, real-time sensors were placed in a working swine confinement and allowed to monitor the air for temperature, relative humidity, particulates, and ammonia. The measurements made with these instruments were compared to established sampling methods. A comparison of the sensor measurements with those made with established methods revealed a close fit to temperature measurements, a reasonably good fit to relative humidity measurements, and poor fits to both particulate and ammonia measurements.

Despite their wide use, a number of studies have indicated that aerosol photometers are often inaccurate, especially when sensing an air volume that contains a mixture of dust types (O'Brien et al., 1989) or when the particle size distribution of the aerosol changes over time (Willeke and Baron, 1990). Furthermore, the response of these instruments is not constant for all particle sizes and diminishes sharply for particles with a diameter greater than 2 µm (MIE, Inc., 1990). It was also evident from the photometer readings that the sensor's optics were increasingly dirtied during a sample period with a corresponding increase in measured concentrations. A final reason for the poor relationship may be associated with the low dust concentrations found in the confinement room; levels near the lower limit of detection of the instrument. The cleanliness of the study room relative to other facilities of this type (Donham, 1990) may be attributed to the frequent room cleanings conducted every three weeks.

As occurred with the aerosol photometer, there was a steady decrease in the relative accuracy of the ammonia monitor with time. This sensor was most accurate when compared with results associated with using the standard method during the first three months of operation. No attempts were made to clean or service the instrument during the year-long study. There were also difficulties encountered when attempting to carry out the procedures associated with the standard method. This method uses an ion chromatograph to determine the amount of ammonia captured on the silica gel. We found that the type of distilled water and the type of column used in the chromatograph affected the results obtained. In addition, the stated accuracy of the method is +/- 14.5%. Therefore, some of the variation between sensor and method can be attributed to variability in the standard method.

Despite the inaccuracies in the sensor measurements, the continuous recordings made give a qualitative assessment of the variation in contaminant levels in the confinement. Both daily and seasonal differences in sensor readings were evident. Furthermore, these variations were largely a consequence of the ventilation rate through the room.

CONCLUSIONS

This study demonstrated that real-time sensors capable of monitoring both environmental conditions and airborne contaminants could be placed in a working swine confinement without hindering the daily operations within the confinement. These instruments stayed in working order throughout a year of use; however, their accuracies diminished over time. Readings from these instruments were useful for determining the relative changes in contaminant levels as affected by changes in internal temperature and, hence, air flow rate through the confinement. If instruments of this type are to be used in working confinements, they should be serviced at least on a monthly basis. An aerosol photometer capable of compensating for large particles and containing an internal pump to continuously clean the optics is recommended. Future work will involve establishing the direct relationship between contaminant concentrations and air flow rates. This work will lead to the establishment of feedback control methods to minimize contaminant levels while considering the related energy costs associated with an increase in air flow rate.

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