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Final Performance Report for:
Ventilation Control To Reduce Airborne Contaminants

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Abstract

Studies have shown conclusively that airborne contaminant levels in swine confinements are typically of a sufficient level to pose a health hazard to workers in that occupation. In addition to a particulate component that can reach levels of 26 mg/m^3 , gases present in confinements in high amounts include methane, hydrogen sulfide, ammonia, and carbon dioxide. Recognized respiratory diseases of swine farmers include upper airway inflammation, an asthma-like syndrome, and chronic airflow limitations. Ventilation systems associated with swine confinements are largely designed to provide a comfortable climate for the pigs. However, because confinements are operated on a for-profit basis, costs associated with operating the ventilation system are typically kept to a minimum by minimizing fan usage, which results in maintaining high airborne contaminant levels. This research involved the analysis of continuous readings of two environmental parameters, temperature and relative humidity, and two air quality parameters, airborne dust and ammonia, relative to measurements taken by standard sampling methods. Results indicated a relatively good correlation between the real-time temperature and humidity recordings and standard sampling methods but low correlation between sensor-based dust and ammonia measurements and those taken by standard method. Therefore, the use of these monitors as direct-reading instruments for feedback control of airflow rates to mitigate concentration levels is suspect. Robust sensors that are easily calibrated and capable of withstanding the harsh environment of a swine confinement are needed. To simulate the effect of airflow on environmental and quality control parameters, computer software capable of simulating dynamic processes was utilized. The resulting model output was compared and validated with the real-time measurements taken on site with results showing a close agreement between the two. Development of models of this sort show promise in accurately determining the effect of ventilation through a room or building on the resulting indoor air quality expressed in terms of environmental conditions or airborne hazards.

Significant Findings

The aims of this project were to: (1) evaluate the temporal variability of gases and particles near the workers' breathing zone of a confinement building during each day that the building contained animals over a year-long period; (2) represent the confinement building with appropriate mathematical models in order to accurately simulate the relationship between changes in ventilation rate and the subsequent changes in environmental factors, gases and particulates; and (3) use these models to simulate and test various automatic control algorithms designed to mitigate airborne contaminants by increasing flow rates.

The significant findings obtained to date largely pertain to work associated with the first two aims. Several publications, as listed below, have been written on the results associated with those two aims. A subsequent paper will detail results obtained from work associated with the third aim.

Findings associated with Specific Aim 1: During this aspect of the research, real-time sensors were used to continuously monitor both the environmental parameters, temperature and relative humidity, as well as the two airborne contaminants, dust and ammonia, to determine the daily and seasonal variation in these parameters as indicators of the overall quality of air in a working swine confinement building. The measurements made with these instruments were compared to established sampling methods. A relatively good association was obtained between the sensors used to obtain the environmental measurements, temperature and humidity, and their corresponding sampled data. However, the time-weighted average of readings from the sensors for ammonia and airborne dust did not correlate well with measurements derived from active sampling methods and were, therefore, unreliable for indicating accurate concentration levels on a real-time basis. Given their lack of accuracy, readings from these instruments were only useful for determining the relative changes in contaminant levels as affected by changes in internal temperature and, by association, air flow rate through the swine building. An aerosol photometer containing an internal pump to continuously clean the optical sensor is recommended for use under these conditions. Likewise, an ammonia sensor designed to be easily serviceable and calibrated is needed.

Daily measurements in airborne contaminant levels verified the expected result that concentrations were higher during the winter months when ventilation through the building was lowest. These concentrations rarely fluctuated as only the minimum fan speed was used continuously. Fan activation in warmer months demonstrated a causal link between airflow rates and dust concentrations but not ammonia concentrations. Ammonia concentrations fluctuated over the course of the day in many cases, but often not in a pattern directly related to fan activity. This information suggests that changes in airflow rates may be used to mitigate dust concentration levels. However, ammonia concentrations are, perhaps, highly sensitive to other factors such as slight changes in room temperature, animal activity, and the depth of the pit that make it less sensitive to changes in ventilation rates. Although a significant difference between winter and summer months was seen in the levels of the airborne contaminants measured during this study, these levels did not exceed threshold limit values (TLVs) established for total dust and ammonia.

Findings associated with Specific Aim 2: During this aspect of the research, a mathematical model was developed to evaluate the indoor air quality (IAQ) of a swine building ventilation system. Ventilation through the building was provided by a “pit” fan that pulled air down through a slatted floor and out of the building after passing through the air volume below the floor. Two “wall” fans were also used on hot days to aid in cooling the air in the building. The model consists of differential equations describing the dynamic behavior of the room and pit air temperatures, relative humidity, dust concentration, and ammonia concentration. These differential equations were coupled with a model of the electronic controller governing the fans and room heater. The numerical solutions from the model were produced using an icon-based software package that greatly simplified the development of this complex model. Since the fans and heater are controlled specifically to maintain indoor temperatures near a desired level, the numerical model was validated by comparing the numerical results obtained for indoor temperature with experimental results. Data for a 5-day period and three kinds of whole-day periods, namely, cold, mild, and hot weather conditions were used for this validation process. To achieve agreement between the model and experimental data, some of the input parameters were modified in a systematic manner to evaluate the impact of each parameter on the model results.

The model proved to be sufficiently complex to allow for reasonable adjustments necessary to reach agreement with the experimental data. The predicted room air temperatures with the modified parameters match closely the data for the three typical cold, mild and hot days and the consecutive five days.

Findings associated with Specific Aim 3: Although work associated with the first Aim occurred in a timely manner relative to the funding period, the development and validation of the simulation model required time and recourses beyond that considered in the original application. Although some modeling was envisioned, it was on a much simpler scale than that which resulted from this work. With the aid of colleagues in the Mechanical Engineering department here, sophisticated computer software was utilized to not only model the fans and their effect on ammonia and dust concentrations, but also the transfer of heat through the walls of the building. This made the simulation far more representative of the actual study site than originally envisioned. A cost function has also been added to the model so that the gain in reducing concentration by increased ventilation can be compared to the loss incurred due to increased energy consumption from operating the fans and/or heater at a higher rate. Given this decision, efforts related to Specific Aim 3 were reallocated toward those associated with Aim 2 and results related to the implementation of Aim 3 have not been fully developed to date. This work will be completed, and manuscript prepared for publication, within the 2002 calendar year.

Usefulness of Findings

Both daily and seasonal variations in indoor air quality (IAQ) within a swine confinement building suggests that, in general, workers need to be aware of the potential for temporary conditions during which the IAQ is exceptionally poor. These conditions are especially apparent in winter months when ventilation is at a minimum. For the study, and most other mechanically ventilated swine buildings, there is no air-conditioning other than increasing the flow of air through the room to cool the air once temperatures rise above a desired level, typically near 72°F. Therefore, low-flow conditions can occur throughout the year whenever the external temperatures drop below that level. Therefore, optimum working times for the purpose of minimizing personal exposure will coincide with the warmest part of the day when fan activity will be highest. These results also indicate that there is a benefit gained in terms of a dilution effect of air contaminants with an increase in fan activity and, therefore, a simple mitigation technique would be to override the automatic fan controller and operate the fans at a high speed for a short period (say, 15 minutes) prior to working in the room. This strategy will markedly decrease worker exposure while minimizing the cost incurred from operating the fans at a high rate for an extended period. A simulation model of the fans, room, controller, and contaminant generation was difficult to develop initially because of the complexity of the model although use of icon-driven simulation software allowed for its development without the need for computer programming skills. Once developed, such a model is extremely useful for simulating a wide variety of potential conditions and their resulting impact on IAQ. Furthermore, a cost-benefit relationship can easily be formulated in relation to the increase in energy costs relative to a decrease in airborne contaminant levels. Because the ventilation system and physical characteristics of the study site are similar to many other industrial settings, this technology can likewise be applied to the analysis of the effect of ventilation systems on IAQ in these settings as well.

List of Publications

1. Zhang L, Smith TF, O'Shaughnessy PT. An examination of three icon-based solvers for ordinary differential equations. Technical Memo: ME-TFS-99-006, 1999. The Department of Mechanical Engineering, The University of Iowa, Iowa City, Iowa.
2. Zhang L, Smith TF, O'Shaughnessy PT. Development of a simulation model for a ventilation system for swine confinement. Proceedings of the Sixth International Livestock Environment Symposium, pp. 293-300. American Society of Agricultural Engineers. 2001 May 21-23, Louisville, KY.
3. Achutan C, Nelson ZE, Karsten AW, O'Shaughnessy PT. Temporal variation in swine confinement indoor air quality. Proceedings of the Sixth International Livestock Environment Symposium, pp. 579-586. American Society of Agricultural Engineers. 2001 May 21-23, Louisville, KY.
4. O'Shaughnessy PT., Achutan C, Karsten AW. Temporal variation of indoor air quality in an enclosed swine confinement. Journal of Agricultural Safety and Health (In press).
5. Zhang L, Smith TF, O'Shaughnessy PT. Development of a simulation model for a ventilation system for a swine building. Transactions of the ASAE (under Review).

Relationship Between Publications and Project Aims

A copy of each of the publications listed above is included with this Report. As shown above, all but #5 have been published or are in the process of being published. #5 was submitted for peer review in May, 2002.

Publications 3 and 4 are directly related to Specific Aim 1: Publication 3 reports the preliminary results associated with work in the swine confinement to determine the daily and seasonal variations in temperature, humidity, ammonia, and dust concentration together with a comprehensive description of the methods used to obtain this information. Results showed efforts made to determine correlations between the standard sampling devices and associated real-time measurements obtained from the direct-reading instruments. Differences in dust concentration recordings between winter and summer months are also given.

Publication 4 expanded on that information by giving a complete summary of all information obtained during the year-long study in the swine confinement. This information demonstrated rather poor performance of the direct-reading instruments for ammonia and dust concentrations. These results bring into question the ability to use such instruments as sensors applied to a feedback control system that relies on their accuracy for making automatic decisions to govern airflow rates relative to contaminant concentrations measured by these sensors. This paper does give evidence, however, for a relationship between airflow changes and corresponding changes in dust concentrations that indicates general ventilation may be a plausible engineering control method for reducing excess levels of this contaminant. Daily changes in ammonia and dust concentrations were given in the form of typical plots. Seasonal changes were described by combining weeks into 4 related seasons and supplying a table of minimum, maximum, and mean values recorded during each season for each variable measured. The correlation between measurements taken by standard sampling techniques and direct-reading instruments were also tabulated by season.

Publications 1, 2, and 5 are related to Specific Aims 2 and 3: Publication 1 describes initial work required to both choose the best available simulation software, and validate its use by comparing the results obtained when using the software to simulate a simple dynamic model defined by a differential equation to results obtained from the models analytical solution. The extremely close results between model and analytical results demonstrated the software's capabilities and application for modeling the far more sophisticated dynamic equations used to model the swine confinement building.

Publication 2 described the differential equations used to describe the changing nature of the indoor temperature, relative humidity, dust concentration, and ammonia concentration. A "two-zone" approach was taken because the total room volume was split by the slatted floor into an occupied room and pit area. Therefore, 8 equations were required. The outdoor temperature was modeled by a sinusoidal function covering a range of temperatures typically seen in the fall. The affect of these temperatures on the indoor variables was presented but this did not include changes in fan flow rates.

Publication 5 describes the complete simulation model with fan controller. However, this publication focused only on indoor temperature since the controller only responds to changes in that variable. The model was validated by supplying a file containing a time-sequence of actual outdoor temperatures, and then compared model output with to the actual, corresponding indoor temperatures. Originally, the model was supplied with starting conditions equivalent to those seen in the room. Some modifications of those conditions was necessary to obtain a close fit between model and actual results. This work demonstrated that the model was not perfect as originally constructed but contained the sophistication necessary to allow changes that brought closer agreement to real measurements.