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Improving Air Quality in Swine Farrowing Operations: Engineering Intervention Results

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ABSTRACT. *Poor indoor air quality inside livestock buildings affects both worker and animal health, and in Midwestern farms during the winter, building contaminants increase as fresh air into the building is reduced to save heating costs. This study has examined using engineering controls to reduce concentrations in an educational swine farrowing building. A recirculating ventilation system (1000 cfm) incorporated one of two dust control options (filtration, cyclone). Respirable and inhalable dust concentrations were significantly reduced: the filtration system performed better than an equivalently-sized cyclone. Room concentrations of hazardous gases were measured to examine whether increased air movement in the room resulted in drawing these contaminants from the manure pits: hydrogen sulfide (H_2S) and ammonia (NH_3) were not increased by using the ventilation system. In year 1, carbon dioxide (CO_2) concentrations averaged 2480 ppm, exceeding the recommended 1540 ppm limit. Mathematical modeling indicated that standard barn heaters generated significant contributions of CO_2. Year 2 operated with heaters that vented combustion gases outside of the room, reducing in-room concentrations (mean = 1420 ppm). The heater itself was associated with 800 ppm CO_2 reduction, while between-winter differences in temperature and pig counts accounted for a 200 ppm CO_2 reduction between study years. Replacing heaters present a low-cost solution to reducing one of the three main air contaminants in this building. Testing the ventilation system in a production barn while tracking human and animal health improvements is under way to demonstrate the cost benefit of these changes to producers.*

Keywords. *Animal Feeding Operations, Dust, Carbon Dioxide, Exposure Control, Farrowing Building, Heaters, Indoor Air Quality, Ventilation.*

Introduction

An estimated 200,000 to 500,000 workers in livestock production buildings are at substantial risk of adverse respiratory outcomes (Pedersen et al. 1996; Larsson et al. 1994, Iversen and Dahl 2000, and others). Eight-hour exposure limits have been recommended for this workforce: 2.4 mg/m^3 for 'total' dust (as measured with a closed-face 37-mm cassette), 0.23 mg/m^3 for respirable dust, 7 ppm for ammonia (NH_3), and 1540 ppm for CO_2 (Donham et al., 1995). Growing evidence identifies new motivation to reduce carbon dioxide (CO_2) in livestock buildings, with declines in cognitive abilities documented at exposures as low as 945 ppm (Allen et al. 2016, Satish et al 2012). These recommended exposure limits are all lower than regulatory (OSHA PELs) and consensus standards (ACGIH TLVs), which were developed for exposures to single compounds in the workplace and which are, by nature, less protective than aggregate exposure recommendations for multiple compounds that elicit similar health outcomes.

Methods

This study evaluated the effectiveness of a recirculating ventilation system to treat dust and the effect of heaters on room CO_2, with concurrent assessment of whether this increased airflow adversely increased the concentration of other hazardous components in the room. This intervention occurred during winter months, in Cedar Rapids, IA, in a single farrowing room. (Figure 1). Two standard 8-inch ducts was used transport room air to the outside dust controller. In winter 1, a filtration unit (Shaker-Dust Collector SDC-140-3, United Air Specialists) was evaluated; in winter 2, a cyclone (Model 16, Donaldson Inc.) was evaluated. Treated air was returned to the room via 10-inch ducts and returned to the room through two 10-inch fabric diffusion ducts (Softflow Diffusers). The air exchange in this study room was 5.4 air changes per hour (1000 cfm). Since simulation models (Anthony et al. 2015) identified the possibility of reducing room CO2 levels by eliminating the source from gas-fired heaters, we examined whether a high-end greenhouse heater could both meet the room heating needs and reduce the CO_2 in the room. The original heaters in the room were Guardian 60 (LB White) and were replaced prior to winter 2 testing with Effinity 93 (Modine Manufacturing) vented heaters.

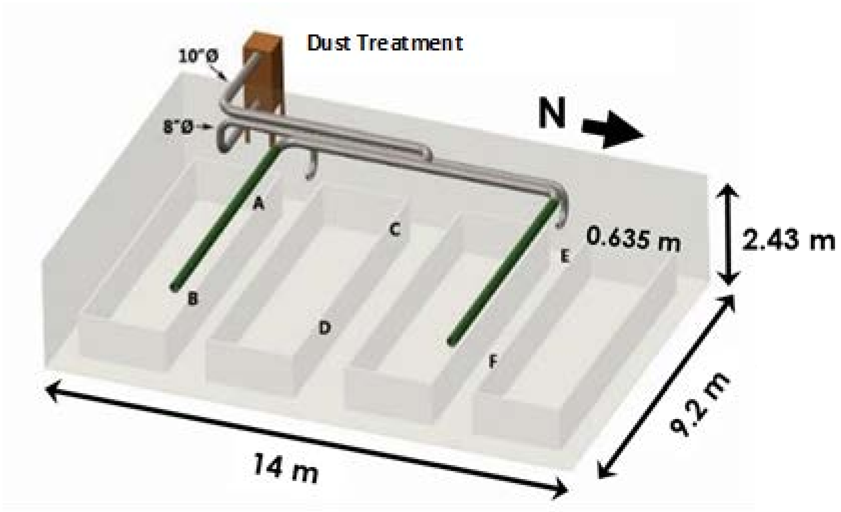

Figure 1. Room layout for farrowing room under study, showing the four rows of crates (running east-west), six sampling positions (A through F), and ventilation intervention that includes exhaust (8"), return air (10"), and diffusion ducts (green). The dust treatment unit is located outside the building.

Twenty-four hour monitoring was conducted on 18 (filtration) and 19 (cyclone) randomly selected days. Monitoring equipment was suspended from the ceiling at six positions (A – F in Figure 1), with inlets positioned at 1.5 m above the floor. Direct reading gas monitors were calibrated and set to datalog every 60-seconds and included: VRae Multi gas (O2, LEL, CO, H_2S, NH_3) and ToxiRae single gas (CO_2 and NH_3) monitors. To account for sensor drift over time, data were logged during 10-minute monitor colocation both before and at the end of each sampling period. Dust was measured using inhalable (IOM, 2 Lpm) and respirable (BGI GLK2.69 cyclones, 4.2 Lpm) sampling heads attached to pumps to obtain a single 24-hour averaged concentration for each sampling day.

Air quality measures were obtained at three periods across each winter, turning the ventilation system off and waiting at least 24 hours to assess "unvented concentrations" for system performance assessments: prior to system operation, midway through the study, and at the end of the study. One-way ANOVA was used to test whether mean dust and gas concentrations were the same between interventions, and generalized linear models with Tukey-Kramer multiple comparisons were used to identify significant differences. Multiple linear regression with backward elimination was used to examine the importance and contribution of multiple CO_2 sources to the room concentration, including animal housing counts, heat lamp use, outside temperature, and heater type. Finally, to examine whether hallway contaminants contributed to room concentrations, Spearman correlation coefficients were computed for gases between rooms and compared between pit fan status (on, off).

Results and Discussion

Mean concentrations for four of the test compounds are given in Table 1. Between year differences in room concentrations were significant for respirable dust and CO_2. Ventilation with dust control was associated with significant and substantial reductions in inhalable dust with both the filtration unit (44% reduction) and the cyclone (32% reduction), however the cyclone was less effective at reducing the respirable dust concentration (18%) compared to the filtration unit (32%). While a cyclone may require lower capital and maintenance expenses than a filtration unit, it may not be sufficient to remove the small particles from the room air.No significant increase in H_2S, NH_3, CO, or LEL concentrations were identified by operating the ventilation system, although definite increased concentrations of NH_3 and CO_2 over the winter period were confirmed. No maintenance was needed of these units over the winter, and the maximum pressure drop at the filter (225 Pa) was well under capacity (1000 Pa). The study team and workers in the intervention room identified that the cyclone created a noticeably louder working environment (81 to 83 dBA) than the filtration unit (unmeasured).

Table 1. Mean concentration and significance testing results (ANOVA p) comparing concentrations (a) between winters and (b) within winter between control technologies

	Mean Concentration (ANOVA p)			
	Mean Respirable Dust, mg/m^3	Mean Inhalable Dust, mg/m^3	CO_2, ppm	NH_3, ppm
Winter 1 (traditional heater)	0.15	0.84	2480	10.1
Winter 2 (vented heater)	0.095	0.68	1400	11
Between Year, p	(<0.001)	(0.162)	(<0.001)	*(0.74)*
Winter 1:				
Filtration On	0.13	0.75	2460	11.3
Filtration Off	0.19	0.98	2500	8.3
Between Ventilation Status, p	*(<0.001)*	(0.236)	(0.622)	(0.35)
Winter 2:				
Cyclone On	0.088	0.578	1280	12.2
Cyclone Off	0.11	0.86	1600	9.8
Between Ventilation Status, p	(0.141)	(0.024)	(0.032)	*(0.61)*

One of the two heaters in this intervention room was on during each 24-hour test period. The room CO_2 exceeded the 1540 ppm recommendation on all days throughout the first winter, but only on five of the 19 study days in the second winter with the vented heater (Figure 2(a)). There is a clear relationship between room CO_2 and outside temperatures (Figure 2(b), with concentrations increasing on colder days, particularly with the traditional unvented heater (Yr. 1). Sources contributing to room concentrations included heater type and operation (outdoor temperatures) as well as animal housing numbers. Since these factors varied between study year, linear regression was used to attribute multiple sources to the room CO_2. Equation results contains significant determinants of room CO_2 across these two winters:

$$CO_2\text{, ppm} = 709 - 28.73\ \text{Temp}\ (^{o}\text{C}) + 28.8\ \text{Sow} + 3.8\ \text{Piglet} + 827\ \text{Heater}, \quad (R^2 = 0.92) \tag{1}$$

where Temp is the outside 24-hour average temperature in Celsius, Sow and Piglet is the average sow and piglet count over the 24-hour sampling period, and “heater” has a value of “1” if it is the traditional unvented heater but zero otherwise. The number of heat lamps (inversely proportional to piglet age) was insignificant to the estimation of room CO_2 concentrations.

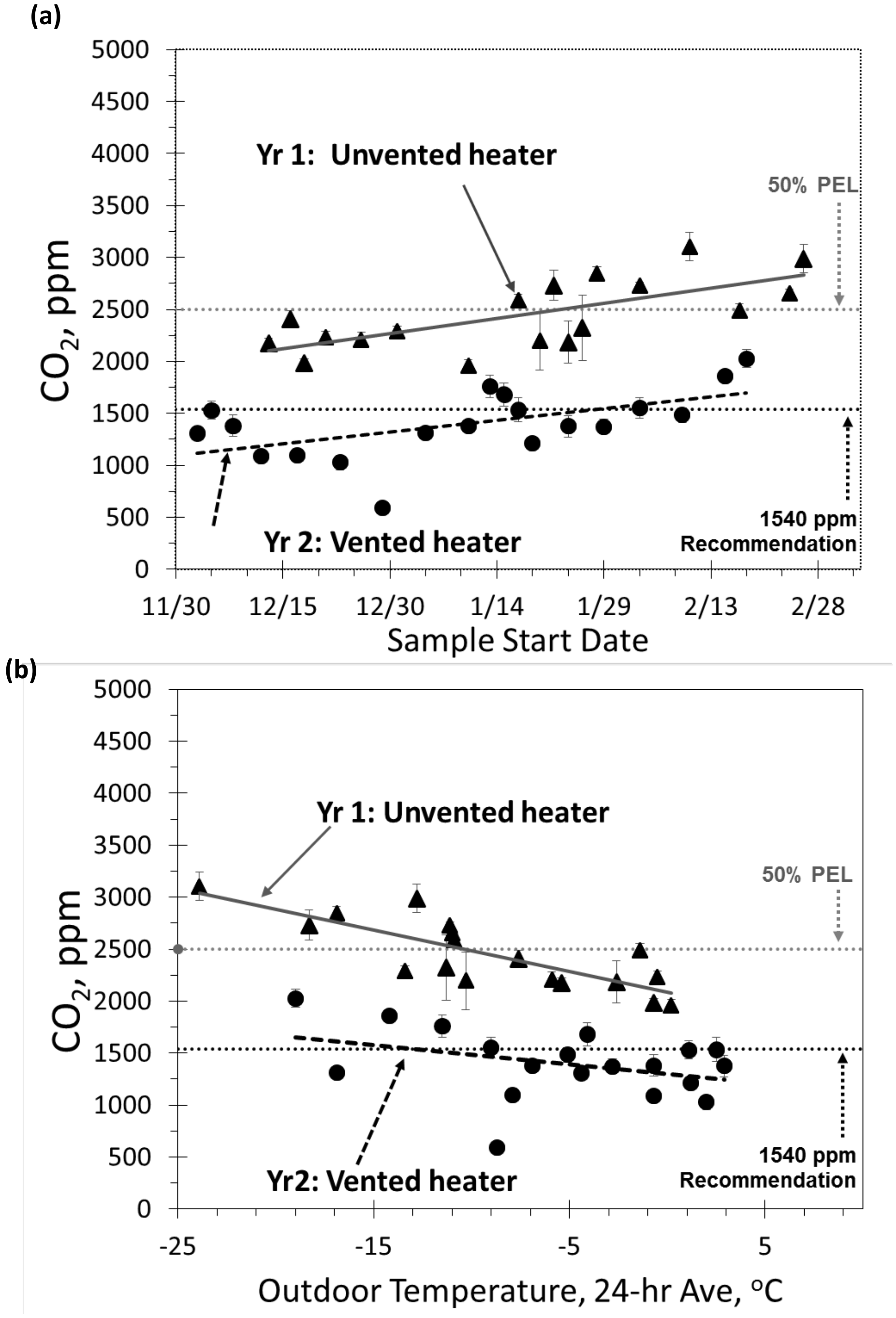

Figure 2. 24-hour mean CO2 in farrowing room by (a) study date and (b) outside temperature.

Equation (1) indicates that the unvented heater contributed approximately 827 ppm to the room CO_2. It is important to note that the other three rooms in the building (hallway, nursery, and a second farrowing room) operated unvented heaters through both winters. Since the manure pit fans were not in operation at the start of the second winter, we could document that contaminated hallway air was the makeup air for the test room when the pit fans were operating using Spearman correlation coefficient changes between hallway and test room by pit fan status for both CO and CO_2.

The livestock building used for this intervention study may not fully represent newer production buildings, which may differ in animal density and insulation, which might affect the relationship provided in equation 1. However, there is sufficient evidence to recommend considering upgrading heaters to improve the air quality inside production buildings, to protect workers and livestock.

Conclusion

The recirculating ventilation system, operating at 5.4 air changes per hour, with dust filtration provided substantial and significant reductions in room concentrations of dust. Using gas-fired heaters that transport combustion products to the outside rather than merely releasing them into the room can significantly and substantially reduce CO_2 concentrations.

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