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Wintertime factors affecting contaminant distribution in farrowing barns

Kelsie Ann Reeve
University of Iowa

WINTERTIME FACTORS AFFECTING CONTAMINANT DISTRIBUTION IN FARROWING BARNS

by

Kelsie Ann Reeve

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Thesis Supervisor: Assistant Professor T. Renée Anthony

Graduate College
The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Kelsie Ann Reeve

has been approved by the Examining Committee
for the thesis requirement for the Master of Science
degree in Occupational and Environmental Health at the July 2012 graduation.

Thesis Committee: ___________________________________
T. Renée Anthony, Thesis Supervisor

____
Thomas M. Peters

____
Matthew W. Nonnenmann

To my amazing family, thank you for your support

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ABSTRACT

Respirable dust, carbon dioxide, ammonia, hydrogen sulfide, and carbon monoxide concentrations were measured using fixed-area monitoring and contaminant mapping in a 19-crate farrowing room during the winter. Direct-reading instruments were used with fixed-area stations and contaminant mapping to evaluate concentrations during five days over a period of a three-week farrowing cycle. Concentrations were evaluated to determine the effect of the pit ventilation on contaminant concentrations, a change in concentration occurred over a sample day, and to determine if three data collection methods produce different daily respirable dust concentrations.

Pit ventilation did have a significant effect on contaminant concentration in a farrowing barn during winter. Compared to when the pit fan was on, mean area contaminant concentration, with the exception of CO, was significantly higher when the pit fan was turned off ($p<0.001$). Mean respirable dust concentration was 79% higher, CO_2 concentration was 35% higher, NH_3 increased from 0.03 ppm to 10.8 ppm, and H_2S concentrations increased from 0.03 ppm to 0.67 ppm. A significant change in area respirable dust ($p<0.001$) and CO_2 ($p<0.001$) mean concentrations occurred over time throughout the course of a sample day. Mean area respirable dust concentrations were highest in the beginning of the sample day and decreased by 77 % (pit fan off) to 87% (pit fan on) over a five-hour sample period. Higher concentrations were likely attributed to the feeding period that occurred early in the day. When the pit fan was turned off, mean area CO_2 concentrations increased by 24% by the end of the sample day due to the inefficient ventilation and the constant production of CO_2 generated by the swine. Finally, comparing the three data collection methods produced similar results concerning

the ranking of the daily mean concentrations of respirable dust; however, differences were seen in the magnitude of the daily average respirable dust concentrations across the three data collection methods, which might lead to different interpretations of risk. To ensure risk is not underestimated, multiple fixed-area monitors are recommended to characterize room concentrations.

Throughout the study, contaminant concentration did not exceed regulatory or international consensus standards; however, recommended agricultural health limits suggested in the literature were exceeded for respirable dust, CO_2, and NH_3. These findings indicate the need to consider personal exposures to those working in farrowing barns and control options to reduce these contaminant concentrations in production facilities.

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LITERATURE REVIEW

Swine CAFOs

Current Trends in the Swine Industry

The swine industry in the United States has changed over the past five decades. Average herd size has increased from approximately 20 head in the mid-1900s to 766 head in the year 2002, while the number of farms has steadily decreased. In 2006, the number of sites was less than one-quarter of the number of swine sites reported in 1990. Alternatively, 2006 estimated inventory levels were 14.8 percent above inventory levels in 1990 (US Department of Agriculture, 2006). Feeding operations where many animals are raised in confined situations are called concentrated animal feeding operations (CAFOs) when the US Environmental Protection Agency's (EPA) criteria are met (US EPA, 2011). CAFOs allow large scale production operations on relatively small land areas. Sites with inventory of 2,000 head or more has increased from 2.1 percent to 11.7 percent between the years 1993 to 2006 (US Department of Agriculture, 2006).

A shift to large-scale production has affected the worker's schedule and the time spent in CAFOs. Swine facilities have evolved from small operations where workers spend a portion of the day performing tasks managing swine to where there is a requirement for full-time work in large intensive facilities (Merchant et al., 2002; O'Shaughnessy et al., 2010; Pedersen et al., 2000; Takai et al., 1998). In CAFO facilities, swine take residence in individual pens in fully enclosed structures that frequently have ineffective ventilation (Schwartz et al., 1992), contributing to poor indoor air quality creating worker health hazards (Wang et al., 2002). Multiple phases in production take place in swine CAFOs. CAFOs may incorporate several or specialize in a single production phase. Sows are bred and remain in pens approximately three months during the gestation phase. Farrowing is a term used for sows giving birth, typically to eight to twelve piglets. Just before giving birth, sows are placed in a temperature-controlled room. For protection, sows are housed in a restrictive crate, limiting movement to avoid crushing the piglets. In most operations the piglets are weaned from the sow at two to three weeks. After weaning, pigs are placed in a temperature-controlled nursery to keep the pigs warm and dry. Here the pigs stay for six to ten weeks and are transferred to a grow-finishing phase where the pigs are fed until market weight is reached (US EPA, 2012). Workers in farrowing units spend proportionally the longest time in CAFO buildings performing specialized tasks over the course of a work day (O'Shaughnessy et al., 2010). Operator duties in a typical modern swine production facility, specifically a farrowing unit, include feeding, sow handling, treating and processing piglets, weaning, and maintaining and cleaning the equipment and structures by assembling and disassembling the farrowing crates, feeders, and floor mats in preparation of washing (O'Shaughnessy et al., 2010).

Contaminant Concentration Variation in Swine CAFOs

Animal density in swine CAFOs affects worker schedules (more swine, longer duration in buildings) but may also affect contaminant concentration inside swine buildings (Donham et al., 1990; Takai et al., 1998), specifically dusts and waste gases generated by the contained swine. Primary gases present in CAFOs include hydrogen sulfide (H_2S), ammonia (NH_3), methane (CH_4), carbon dioxide (CO_2), and carbon monoxide (CO). These hazardous gases are produced by degenerating manure along with animal respiration and heating systems as additional sources for CO_2 and CO. Concentrations of dust and gaseous contaminants differ depending on factors including management and ventilation practices, size of operation, feed and waste handling procedures, as well as season and tasks included in a work shift (Donham, 2010; Duchaine et al., 2000). O'Shaughnessy et al. (2010) found that dust concentrations differed between tasks performed during the farrowing and gestation processes and differences between seasons were also apparent with winter concentrations being the highest.

The highest contaminant concentrations occur during winter due to lower ventilation rates to maintain temperature (Donham, 2010; Wang et al., 2002) and reduce heating costs (Duchaine et al., 2000; O'Shaughnessy et al, 2002). Duchaine et al. (2000) found that NH_3, CO_2, and total dust levels were significantly higher in winter compared to summer. Another factor increasing concentrations and worker exposure, specifically for dust, are tasks performed during a work shift involving the movement of the animals, handling manure, and cleaning the facilities (Donham, 2010; Gustafsson, 1999; O'Shaughnessy et al., 2002; O'Shaughnessy et al., 2010). Jerez et al. (2008) suggested that the variation in dust concentration during winter was significant due to the feed location, level of activity, and pen condition. Studies have also concluded that, due to the swine's increased activity dust concentrations are higher during the day compared to night hours (Gustafsson, 1999; Takai et al., 1998; Wang et al., 2002).

Hazardous gas and dust concentrations in swine CAFOs have been measured in agricultural studies. Mean area total dust concentrations in farrowing, nursery/growing, and finishing buildings ranged from 3.15 mg/m^3 to 15.3 mg/m^3. The farrowing buildings generated the lowest total dust concentrations and the finishing buildings generated the highest concentrations. Respirable dust concentrations ranged from 0.34 mg/m^3 to 0.92 mg/m^3 for the different buildings. The farrowing buildings generated the lowest respirable dust concentrations while the finishing generated the highest concentrations; however, the farrowing buildings had the highest mean respirable fraction (10.7%) suggesting a larger proportion of the dust particles in buildings that house younger pigs were respirable in size (Donham et al., 1986). A study in Northern Europe found the overall mean inhalable dust concentration of sow gestation and fattening (finishing) buildings was 2.19 mg/m^3 and respirable dust was 0.23 mg/m^3 measured over winter and summer (Takai et al., 1998). Clark and McQuitty (1988) found that in farrowing buildings, area dust concentration exhibited large daily fluctuations and dust particles of sizes larger than 5 μm were not present in large quantities during winter. Mean total dust concentration for a swine nursery in the summer was 0.72 mg/m^3, ranging from 0.12 mg/m^3 to 2.14 mg/m^3. Dust concentrations in the swine nursery exhibited significant variability over time and space (Maghirang et al., 1997).

Clark and McQuitty (1988) measured daily NH_3 averages of 10 to 50 ppm in a farrowing building in winter. Integrated wintertime measurements of NH_3 in swine farrowing, growing, and finishing buildings ranged from mean concentrations of 20.3 ppm to 42.2 ppm with the highest mean concentration found in the farrowing buildings in a study done by Donham et al. (1985). Additionally, this study found mean H_2S concentrations between 1.0 ppm and 1.7 ppm with the highest mean concentration found in the farrowing buildings, and CO concentrations ranged from 4.0 to 17.3 ppm with the highest concentrations found in the growing buildings. Carbon dioxide levels in this study ranged from 1338 ppm to 1838 ppm, again with the highest concentrations found in the farrowing buildings. In a wintertime test of air quality in farrowing barns, Clark and McQuitty (1988) found daily averages of CO_2 under 3000 ppm and traces of H_2S were identified, yielding ambient peak concentration of 0.63 ppm in one of the farrowing barns.

Health Effects

Exposures and Worker Health

There is direct evidence that occupational exposures within CAFOs are harmful to human health, particularly respiratory diseases from occupational exposure to individual and complex mixtures of contaminants inside CAFOs (Merchant et al., 2002).

The major source of gaseous contaminants in swine confinement buildings is the manure that is stored beneath the floor in storage pits. Ammonia is a gas produced by aerobic and anaerobic bacterial activity in manure and of the gases present in CAFOs, NH_3 most commonly exceeded threshold limit values (Donham et al., 1985; Donham et al., 1989). Exposure to NH_3 may be irritating to the eyes, throat, and lungs, causing immediate irritation to the nose and throat at levels above 50 ppm (ASTDR, 2004). Hydrogen sulfide is considered the most dangerous gas among the decomposition by-products of manure that can be detected at low levels due to the characteristic odor of rotten eggs. Produced from the anaerobic decomposition of organic materials, it is released from stored manure and is most dangerous when released from agitated liquid manure, producing levels greater than 500 ppm. Ambient concentrations of H_2S commonly found at 10 ppm acts as an irritant to the eyes and respiratory tract (Donham et al., 1982).

Another contaminant of concern is dust. In CAFOs, dust is primarily organic and is a mixture of feed, feces, and additional agents such as hair and shed skin produced from the animals. The larger dust particles originate from the feed grains and the smaller size of the fecal material poses a larger burden on the small airways and alveoli (Donham and Gustafson, 1982; Donham, 1986). Heber et al. (1988) examined size distribution of dust in swine finishing buildings and concluded that feed was the major source of airborne dust. Predicala and Maghirang (2003) compared inhalable and total dust samplers in both a nursery unit and finishing barn: inhalable dust concentrations were higher than total dust concentrations in the finishing barns, but an opposite relationship occurred in the nursery unit indicating that the finishing barns produce larger sized dust particles.

Additional gaseous contaminants in confinement buildings include CO_2 and CO. Although not produced in toxic concentrations from manure, CO_2 and CO is emitted by heaters that are used during winter, and CO_2 is generated by animal respiration. Carbon dioxide is not likely to be a cause of acute toxicity but toxicity data show that a value over 40,000 ppm is immediately dangerous to life and health (NIOSH, 1996). Carbon dioxide has the ability to displace oxygen and has been used as a parameter to determine the minimum ventilation rate. NIOSH (1994) documented 1,200 ppm as the immediately dangerous to life or health concentration for CO based on acute inhalation toxicity data.

Both chronic and acute respiratory diseases are associated with occupational exposure to contaminants found in confinement operations. Research in Europe has found that work-related respiratory symptoms are associated with daily hours spent working in confinement buildings, having a clear dose-response relationship (Radon et al., 2001). A study in Canada found a significant increase in the prevalence of chronic bronchitis and airflow obstruction in swine confinement workers compared to non-farming referents. Higher prevalence of chronic bronchitis was also noted in workers who spent more than three hours per day in the swine building (Cormier et al., 1991). Donham et al. (1995) found a positive correlation between a change in pulmonary function (FEV_1) of all subjects across one shift and total dust, respirable dust, and ammonia exposure in a study involving 207 swine producers. The reduction in pulmonary function was more significant for those who worked six or more years, indicating a chronic dose-response relationship.

Signs of bronchial inflammation were found among twenty swine confinement workers with a mean duration of pig farming work of 23 years (Larsson et al., 1992). A similar outcome was seen in a study that involved 27 nonsmoking pig farmers (Pedersen et al., 1996), suggesting bronchial inflammation in pig farmers may be an early sign of bronchitis. Findings by Schwartz et al. (1992) support observations that asthma and bronchitis are positively correlated with working in swine confinement. Additional health effects have been associated with swine worker exposures including an accelerated decline in forced expiratory volume in one second (FEV_1) (Iverson and Dahl, 2000) and bronchial hyperresponsiveness (Vogelzang et al., 2000).

Standards and Recommendations

Occupational Standards

The Occupational Safety and Health Association (OSHA), the National Institute of Occupational Safety and Health (NIOSH), the American Council of Government Industrial Hygienists (ACGIH), and the American Society of Heating, Refrigerating and

Air-conditioning Engineers (ASHRAE) have exposure limits for select hazardous contaminants workers are exposed to in swine facilities. In order to protect workers, OSHA established eight-hour time-weighted-average permissible exposure limits (PELs) for NH_3 at 50 ppm, H_2S at 10 ppm, CO at 50 ppm, CO_2 at 5000 ppm, and respirable particles at 5 mg/m^3 (OSHA). NIOSH recommended exposure limits (RELs) for occupational health are 25 ppm for NH_3, 10 ppm for H_2S, and 35 ppm for CO (National Institute of Occupational Safety and Health, 2003). ACGIH recommended threshold limits values (TLV) at 25 ppm for NH_3, 1 ppm for H_2S, 25 ppm and 5000 ppm for CO and CO_2, respectively, and 3 mg/m^3 for respirable particles (ACGIH, 2010). ASHRAE recommended indoor air quality concentrations limits of 9 ppm for CO (ASHRAE, 2010) and approximately 700 ppm above the outdoor air concentration for $CO_{2,}$ where acceptable outdoor concentrations typically range from 300 ppm to 500 ppm (ASHRAE, 1999).

Exposure limits are based on time-weighted averages of an eight-hour shift, with the exception of ASHRAE's recommended continuous concentrations which are not based on health risks but are surrogates for human comfort and are used to design and evaluate indoor environments for workers. There are obvious implications that arise from applying occupational exposure limits to workers in swine CAFOs. Exposure limits have not been promulgated specifically to protect the health of livestock production workers due to extended work schedules (Merchant et al., 2002). Independently these airborne contaminants may have an effect on worker health; however, exposure to a complex mixture of various contaminants may create a heightened effect. ACGIH states that when mixed exposures are present and where health outcomes from multiple contaminants are similar, the effects should be considered additive (ACGIH, 2010). It was suggested that lower threshold limit values recommended by ACGIH be established for workers in agricultural environments (Reynolds et al., 1996).

Recommendations

Due to factors not addressed when applying exposure limits to confinement operations, recommendations for maximum concentrations are suggested in the literature. Donham et al. (1989) suggests that concentrations should be maintained below 0.23 mg/m^3 for respirable dust, 2.4 mg/m^3 for total dust, 7 ppm for ammonia, and 1540 ppm for CO_2 to prevent a decrease in pulmonary function. Additionally, a recommended total dust concentration that is considered a guideline for worker health is 2.8 mg/m^3 (Donham et al., 1995) and 2.5 mg/m^3 (Reynolds et al., 1996) and a recommended ammonia concentration should not exceed 7.5 ppm (Donham et al., 1995; Reynolds et al., 1996).

Exposure Assessment

Direct-Reading Instruments

Direct measurement allows contaminant concentration to be measured in the ambient workplace. Direct-reading instruments provide near-instantaneous, continuous feedback of measurement data for the evaluation of workplace hazards. Providing a rapid response, direct-reading instruments allow the determination of hazard profiles for prompt intervention. Direct-reading instruments have become common for assessing hazards in the workplace, including swine operations. O'Shaughnessy et al. (2010) used an aerosol photometer to develop a task-specific concentration profile of a worker's exposure to respirable dust. O'Shaughnessy et al. (2002) applied real-time sensors to assess temporal variability in dust and NH_3 concentrations by day and season also assessing the accuracy of real-time sensors relative to traditional integrative sampling. In a previous study looking at the indoor air quality, Clark and McQuitty (1988) applied direct-reading instruments to detect contaminant concentrations in five farrowing barns.

Contaminant Mapping

An application for direct-reading instruments, due to their portability and logging ability, involves hazard mapping. Hazard mapping requires measuring the contaminant concentration over series of subdivided areas throughout a workplace. Peters et al. (2006) applied exposure mapping in an engine machining and assembly plant using direct-reading instruments to measure particle number and mass concentration to identify contaminant sources. O'Brien (2003) mapped aerosol concentrations in a machining plant and Evans et al. (2008) mapped particle concentrations in an automotive grey iron foundry. Concentration mapping has also been applied in swine operations. Jerez et al. (2008) applied mapping to address the spatial distribution of the average total suspended particulate matter, PM_5, and PM_{10} while Wang et al. (2002) used concentration mapping to determine the effect of ventilation rate and diurnal change of weather on the spatial distribution of dust. Contaminant mapping is useful to the exposure assessment process by assisting in the development of intervention, and evaluation of controls; however, mapping introduces uncertainties as to how to resolve both the spatial and temporal variability that accompanies this method (Koehler and Volckens, 2011).

Control Strategies

Current Practices

Control strategies for CAFO operations include management practices, engineering controls, and personal protective equipment. Included in these strategies are facility cleaning, maintained ventilation systems, and respiratory protection. Studies have shown low rates of respirator use. It was found that among 301 swine producers working inside a barn, 30% reported using face-filtering respirators (Zejda et al., 1993) and results of a survey of 1493 Midwestern farmers concerning personal protective equipment use showed that out of 478 farmers working in animal confinement housing, fewer than 3% reported wearing any respiratory protection always or most of the time (Carpenter et al., 2002).

Due to reliance on worker behavior, personal respiratory protection is not a solitary effective means to reduce exposure. Application of ventilation control measures is a practical solution to improve air quality in confinement buildings. Ventilation systems, however, have been implemented with the primary goal to maintain a constant temperature and not to manage contaminants (Hinz and Linke, 1998). Handbooks have been made to provide agricultural engineering recommendations for swine producers. Recommendations are based on the necessities of an efficient swine operation which does not take worker health into consideration.

Objectives

The purpose of this study is to demonstrate the distribution of contaminants during winter in a farrowing barn. The specific aims are:

1. Determine the difference in contaminant concentration with and without the operation of the manure pit fan
2. Determine if contaminant concentration changes over time throughout the course of a sample day

3. Determine the agreement between data collection methods; applying one representative fixed-area station, multiple fixed-area stations, and a contaminant mapping technique determining contaminant distribution throughout an entire barn over a specified time period

CHAPTER II

FARROWING BARN ASSESSMENT

Introduction

The swine industry has transformed from managing small herds to large-scale, confined feeding operations over the past five decades (USDA, 2006). Chronic and acute respiratory diseases have been found to be associated with work in confinement operations. Studies have identified an increase in the prevalence of chronic bronchitis and airflow obstruction in swine workers who work in both farrowing and fattening (finishing) productions (Cormier et al., 1991), a decrement in pulmonary function (FEV_1) over a workshift (Donham et al., 1995), signs of bronchial inflammation in swine workers compared to a reference group (Larsson et al., 1992), an accelerated decline in FEV_1 in swine workers with an average of 5 daily working hours in a confinement building (Iverson and Dahl, 2000), and bronchial hyperresponsiveness (Vogelzang et al., 2000). Findings from previous studies indicate the need for reduction of exposure inside confinement operations.

In order to reduce heating costs during winter swine confinement operations are closed, functioning with minimal ventilation supplied by small wall exhaust fans and manure pit fans positioned under slotted floors. Gaseous contaminants can be controlled by applying an exhaust fan below the floor, also known as pit ventilation. Two methods are generally used; isolated pit fans that are not connected to a duct, and a pit fan that is connected to a perforated plenum that is installed below the floor. Pit fans connected to perforated plenums can reduce the gas concentrations more effectively than an isolated pit fan due to the increased number of exhaust points. Properly designed ventilation systems that are operated correctly assist in preventing a worker's overexposure by diluting or removing toxic gases while fresh air enters the building to make up for exhausted air via the pit fans. When this system fails, toxic gas concentrations increase due to the lack of fresh air dilution (ASAE EP470, 1992). One limitation of localized exhaust is the short distance that is influenced by the air outlet due to the fact that the capture velocity decreases inversely with the square of the distance from the outlet (ACGIH, 2007).

Lower ventilation rates contribute to higher contaminant concentration in swine CAFOs and personal exposure to these contaminants which has been investigated in previous studies conducted during winter months (Clark and McQuitty, 1988; Duchaine et al., 2000; Jerez et al., 2008; O'Shaughnessy et al., 2002; O'Shaughnessy et al., 2010; Wang et al., 2002). Contaminant total mean concentrations of ammonia (NH_3), carbon dioxide (CO_2), hydrogen sulfide (H_2S), and dust approached exposure limits in a farrowing building (Clark and McQuitty,1988), even though the recorded daily mean ventilation rate for the combined barns was 146% higher than the recommended value of 9.5 L/s per sow (Midwest Plan Service, 1983) and 95% higher than the acceptable ventilation rate of 12 L/s per sow suggested by the author. Duchaine et al. (2000) found increased concentrations of CO_2, NH_3, and dust during winter compared to summer in swine fattening operations. O'Shaughnessy et al. (2002) found that area airborne dust and ammonia concentrations increased during the colder months in a farrowing building, and in a task-specific assessment of a worker's personal exposure to dust in gestation and farrowing buildings (O'Shaughnessy et al., 2010), it was found that personal inhalable dust concentrations were significantly higher in winter compared to spring and summer.

Contaminant concentration is also affected by pit ventilation. Breum et al. (1990) found that a pit ventilation system had better NH_3 removal at an airflow rate of 2400 m^3/hr compared to an above-floor exhaust system operating at approximately the same rate. Considering the general increase in contaminant concentration during cold weather and the importance of the manure pits fans for contaminant control, an assessment is needed to observe the effect pit fan operation has on contaminant distribution in a farrowing room during winter.

Data collection methods to assess contaminant concentration vary across studies, but one common method incorporates measuring contaminant concentrations at one or two locations within the building (Clark and McQuitty, 1987; Donham et al., 1989; Duchaine et al., 2000; Gustafsson, 1999; Heber et al., 1988; O'Shaughnessy et al., 2002), particularly to determine a representative particle concentration. Clark and McQuitty (1988) measured dust concentration at one representative location, and O'Shaughnessy et al. (2002) measured total and respirable dust at one central location in mechanically ventilated farrowing barns. Area total and respirable dust samples were taken at two locations that represented the typical working environment in swine confinement buildings (Donham et al., 1989). The representative location to measure total dust concentration in a swine fattening operation was chosen due to the close proximity to the sources of contamination while maintaining the furthest distance from ventilation sources (Duchaine et al., 2000).

Single fixed-area sampling may be useful if the spatial distribution of particles was uniform throughout the building, but studies found significant variation in particle concentration. Jerez et al. (2008) found statistically significant differences between average total suspended particle concentrations among sampling locations within cross sections and elevations in a wean-to-finish swine building. Wang et al. (2002) found that the spatial variation in total dust concentration distribution was affected by both ventilation rate and diurnal change. Spatial variability assessed for inhalable dust concentrations inside a fattening piggery by Hinz and Linke (1998), found lower concentrations in the aisles compared to the pens, even though they found an approximate uniform spatial distribution of NH_3 concentrations.

Studies have measured select contaminant concentrations in farrowing buildings, some during winter, but information concerning a worker's potential exposure to contaminants in these buildings with a lack of proper ventilation conditions is lacking and needs to be assessed. Workers spend the majority of their work day inside farrowing buildings; therefore, analyzing wintertime contaminant distribution will provide a baseline for which to evaluate the effectiveness of control techniques. Implementing effective controls may significantly reduce worker exposures throughout the industry. The purpose of this portion of the work was to investigate wintertime contaminant spatial and temporal distribution in a farrowing room with and without the operation of the pit fan. Comparisons of the layout and operation of the sampling test site to other farrowing operations will be made to determine the generalizability of the results obtained from the test site to other farrowing operations.

Methods

Farrowing Barn Representation

Characteristics concerning the physical layout and production operation were surveyed at four farrowing barns (referred to as Barn 1, Barn 2, Barn 3, and the sampling test site) in Iowa between November 2011 and March 2012. Dimensions of the farrowing room, crates, wall exhaust fans, louvers, ceiling inlets, were measured and recorded for each farrowing barn. Air velocity measurements were taken of the wall and pit fans at the sites where fans were running when the visit took place. Outdoor dimensions of wall exhaust fans, pit fans, and farrowing building position relative to surrounding buildings were also measured. All barns were in operation and pigs were present at all farrowing sites visited. Additional information was collected from site managers and employees concerning production, conditions during normal operation, and areas of concern. A qualitative analysis was performed to compare the farrowing barns visited in Iowa to the research facility where the study took place.

Contaminant Distribution Assessment

Test Site Description

The test site consisted of one farrowing room at the Mansfield Swine Education Center at Kirkwood Community College. A previous study at this site (O’Shaughnessy et al., 2002) evaluated air quality when this room was previously divided into two rooms. Three rows of five 1.5 m by 2.4 m crates and one row of four 2 m by 2.4 m crates ran east to west in the 9.2 m x 14 m farrowing room (Figure 1). The bottom of the swine crates sat 0.13 m above the concrete floor. Four wall exhaust fans were located on the north and south walls, regulated by a controller (Airstream model TC5-2V4SA, AP, Assumption, IL) with input from two temperature sensors. Two single unit pressure louvers lined the east wall allowing access to hallway air, and eight pressure activated Bi-Flo inlet vent louvers (RayDot Industries, Cokato, MN) lined the ceiling over the central walk alley allowing attic air to flow into the room.

The site's 80-sow operation produced approximately 1200-1500 hogs per year, typically following a fall and spring farrowing season cycle. During the study there were 14 sows (row A did not contain pigs) on days one through four and 19 sows on day five, with 101 piglets occupying rows B, C, and D. All crates were equipped with an automatic feeder attached to the head of the sow section of the crate. The head of the sow faced the aisles located between rows A and B and rows C and D.

Due to winter temperatures and no wall exhaust through the north and south radial wall fans, a minimal amount of movement of the ceiling and east hallway wall louvers was present. The north and south sidewall fans were covered in plastic, and temperatures were too low to activate these fans throughout the duration of the sample period. The crates were positioned above 0.9 m deep pull-plug manure pits. The two plugs were positioned on the east end of the room and the manure pits were not drained throughout the duration of the sample period. Two pit fan exhaust plenums ran the length of the room under the floor between crate rows A/B and C/D and connected two fixed speed pit fans ($^1/_8$ HP, 60 Hz south pit fan, ¼ HP, 28.75 Hz north pit fan) that were intended to exhaust room air through the manure pits to the outside. For the duration of the sampling, only the north pit fan was operable.

Feeding occurred twice per day (lasting approximately 20 minutes), with an occurrence in the morning between 8:00AM-10:00AM during the five-hour sample period. Other than manually filling the feeders, workers did not spend additional time in the farrowing room until weaning the piglets and cleaning the room in between farrowing cycles.

Procedure

In January, measurements of respirable dust, CO_2, NH_3, H_2S, and CO concentrations were taken from early morning to early afternoon for an approximate sample period of five hours per day. Measurements of pit fan velocity and temperature, at the exhaust, were measured three times throughout each sample day to confirm pit fan operation. Both fixed-area station sampling and contaminant mapping was conducted during each sample day to obtain both spatial and temporal measurements of the contaminant concentrations.

The test site follows an approximate 21-day farrowing cycle. Within this time period, five sample days were randomly selected. The test site operators, unlike in production farms, often turn off the pit ventilation during extreme cold periods. This practice allowed for the control of the pit fan to examine contaminant concentrations at two settings, on and off. Each day was randomly assigned a manure pit fan setting which was set the night before measurements took place.

A photometer (Model pDR-1200, Thermo-Electron Corp., Waltham, MA) provided continuous, real-time mass concentration readings of respirable dust. After warming up for five minutes, all photometers were zeroed using zero air filters and then were collocated in the hallway, running five minutes with the zero air filter on and five minutes with the zero filter off. The photometers were attached to sampling pumps (Model 224-PCXR4, SKC Inc., Eighty Four, PA) operating at 2.0 L/min, calibrated at the test site using a TetraCal Volumetric Airflow Calibrator. Carbon dioxide and temperature were measured using VelociCalc air velocity meters (Model 9555-X, TSI Inc., Shoreview, MN). The air velocity meters were calibrated by the manufacturer and re-calibrated using zero air and 2000 ppm CO_2 calibration gas prior to sampling. Ammonia, H_2S, and CO concentrations were measured using VRae multi-gas monitors (Model 7800, Rae Systems Inc., San Jose, CA). All VRaes were calibrated by the manufacturer and re-calibrated using fresh air and the standard reference gas of NH_3 (25 ppm), H_2S (25 ppm), and CO (50 ppm) prior to each day's sampling. All instruments were set to log data at ten-second intervals.

The photometers, air velocity meters, and multi-gas monitors were collocated in the hallway prior to sampling. Additionally, collocation of the photometers in the hallway and air velocity meters in the middle of the farrowing room was done at the end of the day to evaluate drift in concentrations over the five-hour sample period. Collocated measurements were also used to validate comparable measurements between similar equipment positioned in the same location.

Seven fixed-area stations were positioned throughout the farrowing room, with select instruments (Table 2) suspended in baskets hanging from the ceiling with the equipment inlets attached to a pole approximately 1.7 m above the ground (Figure 2). Instruments were placed at stations at the beginning of the sample day and continuously measured contaminant concentrations until the end of the sample day.

After fixed-area station instruments were positioned, a technician collected two-minute concentration data, using three additional direct-reading instruments (photometer, VelociCalc air velocity meter, VRae multi-gas meter) at 43 sampling positions (Figure 2). Inlets to these instruments were positioned at the breathing zone during the measurements. An event was designated as the amount of time over which the technician completed the two-minute samples at all 43 positions, resulting in an approximate 90 minute event duration.. Each sample day had three sequential contaminant mapping events. The starting positions were randomly preselected for each event survey.

In addition to collecting contaminant concentration data, conditions were recorded for each sample day including the average outside temperature, the average farrowing room temperature, the average outside wind conditions, the number of pigs in the farrowing room, and the age of the piglets. The average farrowing room temperature over the three sample events was measured using the VelociCalc air velocity meter (Model 9555-X, TSI Inc., Shoreview, MN) that was operated during the contaminant mapping, and the average outside wind condition was measured using a rotating vane anemometer (RVA) (Model 5725, TSI Inc., Shoreview, MN), positioned on the exterior west side of the farrowing room approximately 3 m from the pit fan exhaust. This measurement was intended to obtain an indication of the air movement outside of the building to determine which days experienced heavy wind, which may affect building concentrations.

Data Analysis

Prior to analysis, individual day collocation measurements were analyzed to ensure monitor measurements were comparable and to assess measurement drift over the course of a sample day. For each day, measurements from all similar equipment were averaged over pre- and post-sampling collocation periods. Next, individual data were adjusted by instrument by determining the slope from a linear regression of the measured versus the combined instrument average concentration of the collocated data, as all measurements should be the same. Zero-intercepts were used for the photometer and the VelociCalc air velocity meter collocation concentrations, but the VRae multi-gas meters were adjusted using the slope and intercept calculated using linear regression for each individual instrument on each test day (Appendix A).

Descriptive statistics were generated, including daily mean and standard deviation of contaminant concentrations measured within the room. Results were generated for both fixed-area station averages and contaminant mapping measurement averages, by day. To compute the fixed-area mean, the daily arithmetic means were calculated using the average of the three 90-minute event means for each station, and then the overall daily room average concentration was calculated using the daily average concentrations for each station. A daily standard deviation was computed using the daily average concentrations across the fixed stations. The contaminant mapping mean and standard deviation was computed using the average concentration of the three 90-minute event means.

<u>Fixed-Area Stations</u>

For all contaminants (respirable dust, CO_2, NH3, H_2S, CO), average concentrations were calculated for each individual station over the periods matching the 90 minute mapping events. The normality of the distribution of these calculated arithmetic means along with the ln-transformed means were analyzed using a Shapiro-Wilk test. When the assumption of normality was not supported, nonparametric tests were examined along with parametric tests on the unadjusted arithmetic means and the ln-transformed data (Appendix B) when comparing concentrations between tests.

An adjusted Tukey (Tukey-Kramer) test of the least-square means was used to identify differences between pit fan operation status (on/off) and differences in the 90-minute average concentrations over time within a sample day (SAS Version 9.2, SAS Institute Inc., Cary, NC, USA). A Wilcoxon two-sample test was performed to analyze the 90-minute average concentrations between pit fan operation status, due to the fact that the concentrations were neither normal or ln-normal. Because the 90-minute average concentrations over time within a sample day were neither normal or ln-normal, a Kruskal-Wallis test was performed. All statistical tests were evaluated at α = 0.05(Appendix C).

Contaminant Mapping

Mapping software (Surfer Version 10, Golden Software, Golden CO) was used to create distribution maps of respirable dust, CO_2, NH_3, H_2S, and CO concentrations for each sample day. For each position, an average concentration was calculated using the two-minute samples measured in the three events. A Kriging method was first used to create a grid for each contaminant for both contaminant mapping and fixed-area station measurements. The gridded data were used to develop two-dimensional maps of the contaminant distribution in the farrowing barn. A layout of the farrowing barn was positioned over the concentration maps to identify areas of high concentrations (Appendix D).

Comparisons Between Data Collection Methods

To evaluate whether using one representative sampling location provides a similar estimate of room concentration to methods involving multiple sampling locations, three estimates of room average concentrations were generated. Due to the central location and the number of stations at which the photometers were deployed, the comparison will only involve the respirable dust concentrations measured over the five sample days. For each day’s set of three 90-minute event averages, a mean from the single location in the middle of the room, a mean over seven fixed samplers, and a mean for the mapping positions were calculated. Average daily concentrations were ranked in descending order for each data collection method in order to determine if using one long-term (90 minute), seven long-term (90 minute), or 43 short-term (2 minute) sampling positions produced similar results when looking at overall daily average respirable dust concentrations. Finally, these estimates of mean respirable dust concentrations were compared to one-tenth of the occupational exposure limit (OEL) values (Ignacio and Bullock, 2006), namely a respirable dust of 0.3 mg/m^3 (`$^1/_{10}$ ACGIH TLV). Given the three methods to estimate room concentration, we evaluated whether any method would over- or underestimate exposure risk relative to this criteria.

Results

Farrowing Barn Representation

The farrowing barns that were visited in addition to the sampling test site were designated as Barn 1, Barn 2, and Barn 3. The barns ranged in age and size of operation. Barn 1 was established in 1997 producing approximately 31,000 hogs per year. Barn 1 was constructed of eight uniform sized 26-crate rooms forming two rows, connected to a breeding and gestation barn. Barns 2 and 3 were also connected to breeding and gestation barns but were constructed of multiple-sized farrowing rooms. Barn 2 was built in 2006, and the 2,800 sow operation produced 62,000 hogs in 2011. Barn 2 consisted of one 28-crate room and eight 58-crate rooms configured in four rows. Barn 3 was constructed in the late 1980's and a portion was rebuilt in 2003. Barn 3 was a 1000 sow farrow-to-finish operation producing 27,000 hogs per year. Barn 3 was constructed of four six-crate rooms, four 10-crate rooms, five 20-crate rooms, and one 30-crate room.

The three barns followed a three-week farrowing cycle, with sows weaning between 10-12 piglets. Both manual and pneumatic feeding systems were used between the three barns with the feeder positioned on the sow portion of the crate. The farrowing crates were approximately five-feet wide by seven-feet long, set on top of slotted floors that were elevated above manure pits. Both shallow (0.61 m) and deep (2.4 m) manure pits were managed between the three barns. The heat sources specifically used for the piglets in the crates were both heat lamps and heated mats. Production workers at the three visited farrowing barns worked a full shift performing tasks in all of the farrowing rooms throughout the day.

The ventilation practices were also similar between the visited farrowing barns. Air from a heated, interior hallway entered the room through multiple wall louvers that opened when an individual room became negatively pressured. Exhaust fans were positioned on the opposite end of the room. The primary exhaust fan accessed the manure pits through perforated plenums that extended the length of the room. With the exception of Barn 1, thermal sensors were positioned in the room and were managed by a control panel to regulate the exhaust fans. Barns 2 and 3 had air inlets lining the ceiling allowing attic air to enter the room. This was the primary source of dilution air during winter. Space heaters ran in both the farrowing rooms and the hallway to regulate temperature during winter. In the summer, air temperature was regulated by evaporative coolers that were positioned in the hallway. Hallway air was drawn in through wall louvers when the exhaust fans on the opposite wall were running.

Similarities existed between the visited farrowing barns and the test site. The test site was built within the time period the other production farrowing barns were constructed. The test site follows an approximate three week farrowing cycle. Crates of similar size were set on top of slotted grating that was elevated above shallow manure pits. Heat lamps were positioned above the piglet portion of the crates. A manual feeding system was utilized at the test site with the feeding bins positioned on the head side (central aisles) of the sow portion of each crate. Along with hallway, air entered the room through wall louvers, and air from the attic entered the rooms through inlets that line the ceiling above the center aisle. The operation of the exhaust fans was regulated by thermal sensors located throughout the room, managed by a single control panel.

Differences also existed between the visited farrowing barns and the test site. Being a smaller operation, the test site had four rows of crates but due to the small number of crates in each row the room was shorter than the visited barns, with three of the four walls in contact with the outside. In addition to the smaller room, the test site's overall building was smaller. The test site ratio of room volume per sow was noticeably larger compared to the production facilities with the exception of the 10-crate room in barn 3 where the ratio was comparable. Another difference was the layout of the exhaust fans. The manure pit fans were all positioned opposite the main hallway, and opposite of the wall louvers and doors to access the room where air entered the room; however, our test site had sidewall exhaust fans, located on the adjacent walls, perpendicular to the directed airflow, different from most production buildings where sidewalls abutted neighboring farrowing rooms and not the outside. Similar to the visited barns, a heater was located in the hallway to warm the air before it entered the room in winter, but an additional room was located on the other side of the hallway, so evaporative cooling was not used at the test site. For this winter study, however, neither evaporative cooling nor wall fans ran in either production or our test facility. There was a difference in time spent inside the farrowing barn between the workers at the test site and the production farrowing barns. Workers in production spent more time in the farrowing barn, performing tasks in multiple (8 to 13) farrowing rooms.

Contaminant Distribution Assessment

Table 1 outlines the conditions over the five sample days. Average outside temperatures ranged from -0.6°C to 10.6°C proving to be a mild winter season for the Midwest, while indoor farrowing room temperature remained stable (22.9°C to 26.9°C). Outside wind conditions were variable between the sample days. Days four (4.2 m/s) and five (0.8 m/s) experienced the highest and lowest wind speeds. The number of pigs (sows and piglets) did not change over the course of the study period, with the exception of day five when five additional sows were added to row A. A wide range of piglet age was recorded throughout the entire sample period.

Table 3 includes daily room descriptive statistics of the contaminant concentrations that were measured using the fixed-area stations and the contaminant mapping. Respirable dust and CO_2 fixed station and mapping concentrations were the highest during the second sample day when the pit fan was turned off. Minimum respirable dust fixed station and mapping concentrations were measured on the first sample day and minimum CO_2 concentrations for both fixed station and mapping were measured on the fifth sample day. Maximum and minimum mean NH_3, H_2S, and CO concentrations across all sample days were not similar. The daily mean concentration of NH_3 was highest on day five (10.8 ppm) which was a warmer day with the pit fan turned on, also the day when the test site was in full production, and lowest on day three (0.03

ppm) which was a colder day with the pit fan turned on. Hydrogen sulfide concentrations were highest on the fourth sample day when the pit fan was off, and lowest on the first sample day when the pit fan was on, concentrations ranging from 0.03 ppm to 0.67 ppm. Carbon monoxide concentrations were highest on the first sample day, the coldest day when the heaters operated more frequently in the farrowing room, and were lowest on the fifth sample day, a warmer day when the heaters did not cycle on resulting in a maximum difference of 68%; however, this only ranged from 0.91 ppm to 1.53 ppm. Both fixed station and mapping concentrations were similar for the contaminants with the exception of NH_3. Fixed station NH_3 mean concentrations were noticeably higher than the mapping mean for the second, fourth, and fifth sample days. Possibilities arise concerning instrument error as a factor for this difference in NH_3 concentrations. Non-detect concentrations were measured using contaminant mapping for NH_3 and H_2S which could possibly be underestimating the concentration due to the instrument's resolution of 1 ppm.

Table 4 shows that mean concentrations of the contaminants when the pit fan was turned off were significantly higher than mean concentrations when the pit fan was turned on, with the exception of CO, which showed no statistically significant difference. Mean respirable dust, CO_2, and H_2S concentrations were significantly higher when the pit fan was turned off. This result was apparent when using parametric ($p<0.001$) and nonparametric tests on non-transformed ($p<0.001$) and ln-transformed data ($p<0.001$). When the pit fan was turned off, daily area respirable dust concentrations were 79% higher and CO_2 concentrations were 35% higher, at most. Area H_2S concentrations measured on the first and third sample days when the pit fan was turned on were near zero, increasing to a mean area concentration of 0.67 ppm measured on the fourth sample day when the pit fan was turned off. Mean area NH_3 concentrations were also significantly higher when the pit fan was turned off using parametric ($p=0.001$) and nonparametric ($p=0.011$) tests and ln-transformed data ($p=0.001$); however, the highest area mean NH_3 concentration was measured on the fifth sample day when the pit fan was turned on.

The significantly higher contaminant concentration when the pit fan was turned off was apparent when comparing maps created for the contaminant mapping. Figures 3 and 4 are an example of contaminant maps that communicate the difference in the distribution of respirable dust concentration on a day when the pit fan was turned on and a day when it was turned off. Similarly, Figures 5 and 6 show the difference in CO_2 concentration for the same sample days.

Table 5 summarizes the comparison of the 90-minute event means representing the beginning, middle, and end of the sample day for each contaminant when the pit fan was turned off and when the pit fan was turned on. The adjusted Tukey tests of the least-square means showed that on days when the pit fan was turned on there was a statistically significant difference between mean respirable dust concentrations of events two and three ($p<0.001$) and events one and three ($p<0.001$), no statistically significant difference was observed between the mean concentrations of event one and event two ($p=0.717$). An additional contrast was evaluated by grouping events one and two and comparing the two mean concentrations to the event three mean concentration, and a statistically significant difference was found ($p<0.001$). Respirable dust concentrations when the pit fan was turned off showed similar results, with mean respirable dust concentrations differing significantly between events two and three ($p=0.0003$) along with events one and three ($p=0.001$). The contrast performed by grouping events one and two mean concentrations and comparing this grouping to the event three mean concentration resulted in a statistically significant difference ($p<0.001$). Respirable dust concentrations at the end of the sample day were significantly lower than first two 90-minute events. When the pit fan was turned on, the largest decrease in respirable dust concentration from the beginning to the end of the sample day was by 87%, and when the pit fan was turned off, there was a 77% decrease in respirable dust concentration. Due to the difference in feeding time and time when the measurements started, this change in respirable dust concentration occurred at different times over the five sample days.

Differences between event means for CO_2 were also significant for sample days when the pit fan was turned off and turned on. Event one and event two were significantly different when the pit fan was turned on ($p=0.048$) but a statistically significant difference was not observed when comparing events two and three ($p=0.963$) and comparing events one and three ($p=0.085$). A statistically significant difference was found when comparing event one mean concentration and the grouping of events two and three mean concentrations ($p=0.011$). Days when the pit fan was turned off presented differences between event means to a greater extent. Events one and two were significantly different ($p<0.001$) along with events one and three ($p<0.001$). The contrast between event one and the grouping of events two and three were also significantly different ($p<0.001$). Carbon dioxide concentrations during the last two 90-minute events were significantly higher than the beginning of the sample day with a 24% increase in CO_2 concentration across all of the fixed stations from the beginning of the day to the end of the sample day, which occurred on a day that the largest concentrations were measured. No other differences were seen between the event means for NH_3, H_2S, and CO during sample days when the pit fan was turned off and turned on.

The results of the nonparametric Kruskal-Wallis test, which does not require normally distributed data, shown in Table 6, confirmed the results of the adjusted Tukey which does require normally distributed data. These tests showed that there was a statistically significant difference in respirable dust concentration among the three events when the pit fan was turned on ($p<0.001$) and off ($p<0.001$). There was also a difference in CO_2 concentration among the three events when the pit fan was turned on ($p=0.027$) and turned off ($p=0.001$).

Results of the comparison of mean respirable dust concentrations using three data collection methods are shown in Table 7. The three methods identically ranked the daily average concentrations from high to low, with the exception of using one representative fixed-area station which inversely ranked sample days three and five compared to the other two methods. Using multiple fixed-area stations and contaminant mapping measured concentrations above the target respirable dust concentration of 0.3 mg/m^3 ($^1/_{10}$ TLV) for four out of the five sample days and three out of the five sample days, respectively. However, using one representative fixed-area station in the middle of the room, only two of five days had measured daily average concentrations above 0.3 mg/m^3. One centrally located monitor underestimated mean room concentrations, which may affect interpretation of exposure risk.

Discussion

The test site was a farrowing facility with similarities in the operation, physical layout, and ventilation practices to three other farrowing facilities in Iowa. The test site did possess characteristics that differed from the other farrowing barns that may have an effect on contaminant distribution. Three out of the four walls of the test site farrowing room had direct contact with the outside allowing the wall exhaust fans to be positioned perpendicular to the airflow of the room, unlike the production farrowing facilities visited where the wall fans were positioned parallel to the airflow. The positioning of the wall exhaust fans was not relevant to this study as the wall exhaust fans do not normally operate during the winter and were not in operation during the study. Wind and temperature may have had an impact on our results as the walls of the room at the test site had more direct contact with the outside. Another important difference is the larger room volume to sow ratio in the test site. Due to this fact, measurements of contaminant concentrations at the test site may be lower than what may be found at other farrowing facilities. An additional room was positioned on the other side of the hallway at the test site which may bring more contaminated air into the farrowing room compared to the hallways in the production facilities which had direct access to outside air. The test site was a smaller operation but exhibited important qualities that were seen in the additional farrowing barns that will allow the results to be generalizable to farrowing facilities. However, actual concentrations in longer barns with more crates may not be represented by those measured here.

Despite the range of outside temperature observed over the five sample days, indoor farrowing room temperature remained stable (22.9°C to 26.9°C), controlled by the space heaters inside the room, air entering the room through the interior hallway, and the minimal ventilation provided by the pit fans while in operation. The ventilation was able to be controlled by covering the wall exhaust fans in plastic and adjusting the pit fan to provide the minimal ventilation experienced during colder outdoor temperatures.

The fixed-area and mapping contaminant mean concentrations did not exceed the regulatory and international consensus occupational limits; however, respirable dust, CO_2, and NH_3 exceeded recommendations for agricultural health limits suggested in the literature. Measured area mean respirable dust concentrations for all sample days were above the recommended limit of 0.23 mg/m^3 (Donham et al., 1989) and exceeded the $^1/_{10}$ TLV (0.3 mg/m^3) evaluated here. Mean CO_2 concentrations ranged from 2821 ppm to 3804 ppm over all sample days, remaining above the ASHRAE (1999) recommendation of approximately 1000 ppm and Donham et al.'s (1989) recommendation of 1540 ppm to prevent a decrease in pulmonary function; however, the average daily mean concentrations did not surpass the ACGIH TLV (5000 ppm). Area NH_3 mean concentrations were higher than the recommended 7 ppm limit (Donham et al., 1989) for three of the five sample days but were well below the ACGIH TLV (25 ppm).

Operation of the manure pit fan significantly reduced contaminant concentrations, with the exception of CO. An increase in contaminant concentration during the colder months when ventilation rates were low has already been reported. Inherently, when ventilation rates decrease, as in our case when the pit fan was not operating, concentrations will experience a further increase throughout the day. A statistically significant difference was found between mean respirable dust concentrations during days when the pit fan was turned off and turned on, which resulted in a 79% higher dust concentration when the pit fan was turned off. However, in reality the dust control provided may not be sufficient to eliminate the need for secondary exposure prevention methods (i.e. respiratory protection) (maximum area concentration off: 0.54 mg/m^3, minimum area concentration on: 0.30 mg/m^3).

A statistically significant difference was found in CO_2 concentration when the pit fan was turned off with a 35% increase compared to concentrations when the pit fan was turned on. Clark and McQuitty (1987) found daily CO_2 averages of 2570 ppm and 2765 ppm in farrowing barns that maintained a minimal ventilation rate, comparable to the daily average area concentrations measured when the pit fan was on in the current study. The current and previous studies measured CO_2 concentrations above ASHRAE indoor air quality recommended levels indicating potential worker discomfort but is not a determinant for a level that will exhibit a human health response. Carbon dioxide can reach concentrations higher than what was measured in the current study that do have an effect on human health. Prolonged periods of exposure to 15,000 ppm of CO_2 will cause mild health problems while exposure to increased CO_2 levels of 70,000 ppm to 100,000 ppm may produce unconsciousness (ASRAE, 1999).

A statistically significant difference was also measured between pit fan settings in NH_3 and H_2S concentrations, but concentrations remained below the TLV. Mean daily concentration of NH_3 when pit fan was turned on (Table 4) was similar to the area mean concentration of 3.64 ppm (St. Dev.=2.57 ppm) obtained by O'Shaughnessy et al. (2002) in a farrowing building with minimal ventilation in winter. Mean NH_3 concentration measured during days when the pit fan was turned off and during sample day five when the pit fan was turned on exceeded the 7 ppm limit recommended by Donham et al.

(1989). Heightened wintertime levels of NH_3 were found in previous studies (Clark and McQuitty, 1987; Duchaine et al., 2000; Donham et al., 1985) which could be due to differences in the swine operation, the warmer temperatures, and wind conditions during the current study. Farrowing barns with both deep and shallow manure pits were present in the study conducted by Clark and McQuitty (1987), who reported that pits were filled to overflowing in one of the barns and a continuous flow gutter was used in another, both of which may account for the higher NH_3 concentrations. Duchaine et al. (2000) found higher NH_3 concentrations in swine fattening (finishing) operations that housed larger swine and more swine in buildings, having a smaller room volume per pig ratio compared to the current farrowing study. Across all of the contaminants, area concentrations did not surpass the regulatory or international consensus occupational exposure limits; however, concentrations did exceed recommended agricultural limits that take the exposure to complex mixtures in a swine facility into consideration. However, it is important to note that in this operation, the amount of time workers spent in this single room farrowing facility was short.

A statistically significant change in respirable dust and CO_2 concentration occurred over time throughout the course of a sample day both when the pit fan was turned off and turned on; however, the same change over time did not occur for both of the contaminants. The same relationship resulted between the three event mean respirable dust concentrations for days when the pit fan was turned off and turned on. The change in respirable dust concentration over the first two 90-minute events, measured over the first three hours of the sample day, was not statistically significant, but the concentrations measured over the first two events were significantly different than the last event. This statistically significant difference demonstrates that a decrease in respirable dust concentration occurred during the end of the sample day, at most by 87% when the pit fan was turned on and 77% when the pit fan was turned off. This change in respirable dust concentration could be related to the feeding that occurred over the time period during events one and two which agrees with results of previous studies that feed contributes to higher concentrations (Jerez et al., 2008; Heber et al., 1988). Additionally, more activity in the farrowing room occurred during feeding which also contributes to an increase in concentration (Clark and McQuitty, 1987; Jerez et al., 2008; Wang et al., 2002). When the pit fan was not running, the room was found to have a significant increase in area CO_2 concentration during the middle and end of the five-hour sample period, increasing 24% from the beginning to the end of the sample day. Carbon dioxide is generated by swine within the barn, and ventilation is required to eliminate this gas from the room throughout the day. Since ventilation was essentially zero with the pit fan off, an active farrowing room would be expected to experience an increase in CO_2 concentration. Mean concentrations of CO_2 did not differ throughout the day when the pit fan was on to as great of an extent as when the pit fan was turned off. A statistically significant difference was seen between events one and two which at most generated a 15% increase in CO_2 concentration, attributed to the concentrations measured on the third sample day.

The application of multiple data collection methods (one representative fixed-area station, multiple fixed-area stations, and contaminant mapping) produced similar rankings of average daily concentrations; however, a difference in the concentrations was noticed between the three data collection methods when comparing daily concentrations to the target concentration of 0.3 mg/m^3 ($^1/_{10}$ TLV). Using multiple fixed-area stations resulted in the highest daily average concentrations for four out of the five sample days, followed by mapping and using one representative fixed-area station in the middle of the room. This suggests that the application of multiple fixed stations set up over time may capture sufficient variability and quantify higher concentrations which would help make more conservative health protection decisions to control potential worker exposure. The area data collection methods did not assess personal exposure, which has the potential to underestimate worker exposure. Therefore, the most conservative approach should be strongly considered.

Similar to the concept of the three data collection methods, obtaining repeated measurements and analyzing a larger sample size may improve spatial and temporal contaminant resolution. When comparing contaminant concentration, specifically NH_3, during sample days when the pit fan was turned off and turned on, analysis involved comparing daily average concentrations (N=15) and average 90-minute event concentrations (N=45). Analyzing the daily average concentrations did not result in a statistically significant difference in average NH_3 concentration when the pit fan was turned off compared to when the pit fan was turned on (p=0.06). Analyzing the 90-minute event average concentrations produced a statistically significant difference in average NH_3 concentrations between the two pit fan settings (p=0.001) introducing a larger sample size into the analysis and obtaining a better understanding of contaminant distribution in the farrowing room throughout the duration of the entire sample day.

Limitations

Limitations were present in this study and should be considered for future applications. The fact that quantitative data were collected only at one site and physical differences were seen between the test site and other farrowing facilities, uncertainties arise in the generalizability of the results. Data were collected during a five-hour time period ranging from the early morning to the early afternoon for each sample day leaving uncertainty in contaminant concentration for the remainder of the eight hour work day, particularly for contaminants that were found to increase over the five-hour sample day (CO_2).

Contaminant mapping introduces uncertainties in the representation of the map because contaminant concentrations vary across both space and time, and measurements were made over short two-minute periods taking 90 minutes to collect. Error that stemmed from the spatial and temporal variability in contaminant maps was reduced by the collection of repeated measurements throughout a sample day starting at random positions within the farrowing room and the repeated measurements were reproduced for five sample days that were assigned a random manure pit fan setting. Adjustments to account for drift throughout the day were made, but direct-reading instruments present additional measurement error due to precision level, sensitivity, accuracy, and interferences associated with each individual type of instrument. The multi-gas monitor used for contaminant mapping contained an NH_3 sensor that was problematic as near zero concentration measurements were obtained throughout the five sample days. Near zero concentrations were not observed among the other contaminants using the same multi-gas monitor; therefore, the problem source was not the multi-gas monitor. After ruling out incorrect calibration settings, a potential reason for the abnormally low readings may be the multi-gas monitor's low sensitivity to NH_3. An additional potential source for error during the mapping was the response time of the multi-gas monitor's NH_3 sensor (150 seconds). The response time impacts the multi-gas monitor's ability to rapidly measure large concentration changes; however, in the current study, the NH_3 concentrations did not vary either within the two-minute sampling period or between the mapping positions in the room.

The test site had an inoperable manure pit fan on the south side of the building during the study which had the potential to affect contaminant distribution. Farrowing facilities use manure pit fans as the primary means to ventilate the room, operating continuously and concentrations may have been lower with both pit fans on. Due to the importance of the pit ventilation, production facilities would take action and fix complications that arise with this system. Additionally, the crates in row A on the south side of the room were empty until sample day five when sows were introduced which had the potential to affect contaminant concentration by providing an underestimate of contaminant concentration when in full production. This affects the interpretation of risk in farrowing buildings relative to the occupational exposure limits (OELs), suggesting that facilities in full production have the potential to produce higher contaminant concentrations compared to the results in the current study. Error due to the inoperable pit fan and the empty crates may be lessened due to the fact that the empty crates were positioned on the same side (south) of the room as the inoperable pit fan.

Despite these limitations findings are still relevant, particularly in determining the importance of the operation of pit fan to lower contaminant concentration and the difference in the results obtained from using different data collection methods. The generalizability of our results is strengthened by the fact that the test site possessed similar characteristics as other production farrowing facilities. Randomly selecting sample days within a farrowing cycle, assigning a pit fan operation status to each sample day, and randomly selecting event starting positions also strengthen the generalizability. This study analyzed contaminant concentrations measured throughout the course of an entire farrowing cycle involving multiple piglet ages. Both fixed-area station measurements and contaminant mapping were performed monitoring spatial and temporal variability in contaminant concentration. Due to the test site's operation, the pit fan setting could be established and monitored for each sample day to further support the significant effect ventilation has on contaminant levels in a farrowing facility.

Conclusion

Respirable dust, CO_2, NH_3, H_2S, and CO concentrations were measured in fixed-area stations and mapped in a 19-crate farrowing room in winter. Pit fan setting, on and off, was controlled in order to analyze the effect pit ventilation has on contaminant concentration. Respirable dust concentrations were significantly higher in the beginning of the day, when the pit fan was either on or off, due to the feeding. An increase in CO_2 concentration occurred when the pit fan was off due to the lack of attic ventilation effectiveness and the continuance of the swine's CO_2 production. Respirable dust, CO_2, NH_3, and H_2S concentrations were significantly lower with the operation of the pit fan. These observations suggest that the pit fan can effectively reduce contaminant concentrations. Three different methods were used to generate a daily room respirable dust concentration for comparison to determine a sampling approach that will sufficiently variability and a conservative estimate of worker exposure level. The respirable dust concentration measured with the application of multiple fixed-area monitors resulted in the highest concentrations for a majority of the sample days that were above the recommended agricultural exposure limits suggested in the literature. This conservative approach will improve our understanding of worker exposure.

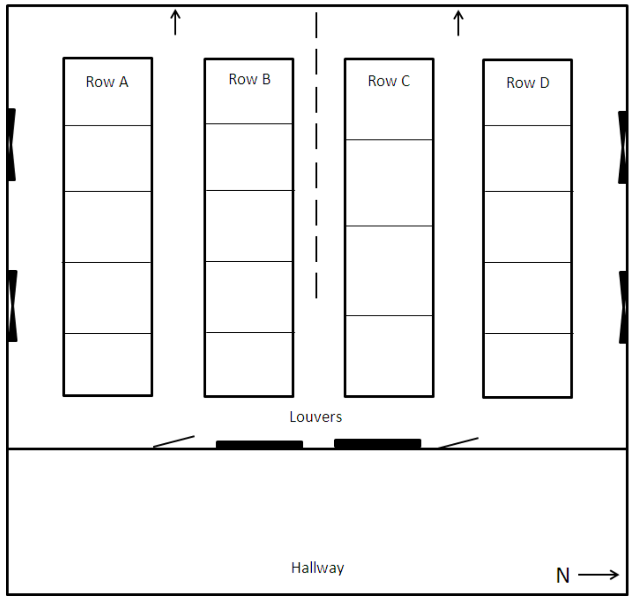

Figure 1. Schematic diagram of the swine farrowing barn.

Table 1. Conditions recorded for each sample day.

Conditions	Day 1	Day 2	Day 3	Day 4	Day 5
Manure Pit Fan Setting	On	Off	On	Off	On
Outside Temperature °C (°F)*	-0.6 (31)	3.3 (38)	0 (32)	10.6 (51)	7.2 (45)
Farrowing Room Temperature °C (°F)**	25.1 (77.2)	24.4 (75.9)	26.9 (80.5)	24.7 (76.5)	22.9 (73.3)
Mean Outside Wind Conditions (Airflow in m/s)***	3.2	2.4	2.1	4.2	0.8
Number of pigs (sows + piglets)	115	115	115	115	120
Range of piglet age (days)	2-11	5-14	8-17	9-18	11-20

*Outside temperature was obtained from http://www.nws.noaa.gov/climate/index.php?wfo=dmx, recording an average temperature for the entire day.

**Farrowing room temperature was calculated using the average temperature measured by the mapping air velocity meter over the duration of the three sample events.

***Outside wind conditions (airflow) was calculated using the average air velocity measured by the rotating vane anemometer set up outside over the duration of the three sample events. This measurement is to give an indication of the speed of the air movement outside of the building to determine which days experienced the most air movement outside over the duration of the sample events.

Table 2. List of instruments that are located in both the fixed-area stations A-G along with the instruments used during the contaminant mapping.

Sampling Location	**Photometer (*p*DR-1200)**	**Air velocity meter (9555-X)**	**Multi-gas meter (VRAE 7800)**
Station A	X	X	
Station B	X		X
Station C	X	X	X
Station D	X		
Station E	X	X	
Station F	X		X
Station G	X	X	
Mapping	X	X	X

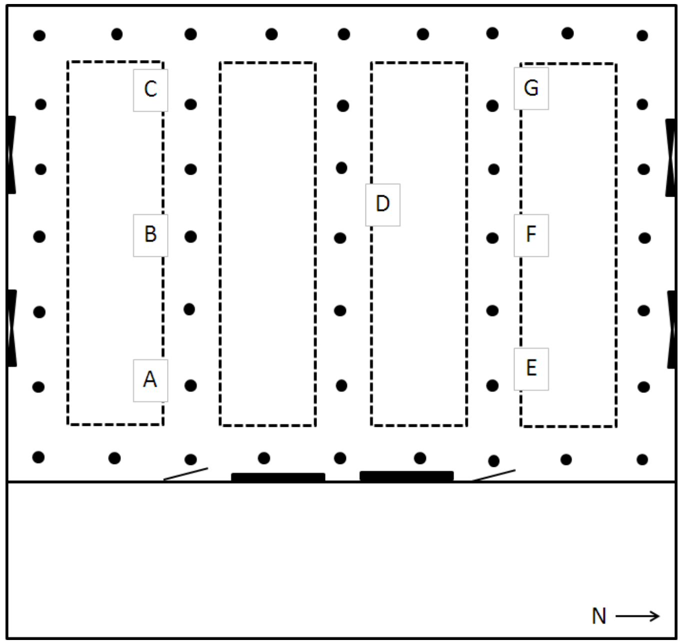

Figure 2. Schematic diagram of the fixed area station and contaminant mapping positions.

Table 3. Descriptive statistics of daily mean (standard deviation) contaminant concentration over all fixed-area stations and contaminant mapping.

	Day 1 (Fan on)	**Day 2 (Fan off)**	**Day 3 (Fan on)**	**Day 4 (Fan off)**	**Day 5 (Fan on)**
Dust, mg/m^3					
Fixed Station	0.30 (0.02)	0.54 (0.06)	0.35 (0.04)	0.39 (0.03)	0.34 (0.04)
Mapping	0.28 (0.04)	0.52 (0.14)	0.34 (0.10)	0.40 (0.02)	0.30 (0.05)
CO_2, ppm					
Fixed Station	2920 (33)	3800 (160)	3050* (120)	3520 (200)	2820 (120)
Mapping	2940 (45)	4000 (430)	3090 (230)	3370 (320)	2710 (42)
NH_3, ppm					
Fixed Station	1.0 (0.6)	8.2 (4.5)	0.03 (0.05)	8.6 (1.4)	10.8 (0.7)
Mapping	0 (0)	1.5 (0.3)	0 (0)	0.02 (0.03)	3.6 (0.8)
H_2S, ppm					
Fixed Station	0 (0)	0.28 (0.05)	0.03 (0.04)	0.67 (0.09)	0.30 (0.11)
Mapping	0 (0)	0.20 (0.08)	0.005 (0.006)	0.61 (0.12)	0.27 (0.11)
CO, ppm					
Fixed Station	1.53 (0.49)	1.00 (0.49)	1.04 (0.69)	1.23 (0.63)	0.91 (0.24)
Mapping	1.30 (0.08)	1.18 (0.03)	1.18 (0.08)	1.07 (0.05)	0.95 (0.21)

* Due to invalid measurements from fixed station G, Day 3 NH_3 fixed station mean and standard deviation is missing data.

Table 4. Comparison of contaminant concentration during sample days when the pit fan was turned off and days when the pit fan was turned on.

	Parametric Statistics				Nonparametric Statistics	
	Adjusted Tukey				Wilcoxon two-sample test	
	No Transformation		LN-Transformed			
	Mean*	**P**	**Mean****	**P**	**Mean Score**	**P**
Dust						
Fan off	0.466	<0.001	-0.797	<0.001	73.2	<0.001
Fan on	0.329		-1.14		39.5	
CO_2						
Fan off	3661	<0.001	8.20	<0.001	47.1	<0.001
Fan on	2920		7.98		19.4	
NH_3						
Fan off	8.36	0.001	2.04	0.001	29.4	0.011
Fan on	3.92		-1.31		18.7	
H_2S						
Fan off	0.479	<0.001	-0.840	<0.001	34.1	<0.001
Fan on	0.109		-4.20		15.6	
CO						
Fan off	1.12	0.783	-0.007	0.963	22.9	0.991
Fan on	1.16		-0.016		23.0	

* Mean was computed using the least-square mean of the data that were not transformed (units mg/m^3 for respirable dust, ppm for all else).

** Mean was computed using the least-square mean of the ln-transformed data (units $\ln(mg/m^3)$ for respirable dust, ln(ppm) for all else).

Table 5. Comparison of the three ln-transformed event means of each contaminant for days when the pit fan was turned off and days when the pit fan was turned on using an adjusted Tukey in the post-hoc analysis.

	Fan On				Fan Off			
	Event	**Mean***	**Comparison**	**P**	**Event**	**Mean***	**Comparison**	**P**
Dust	1	-0.982	1 v 2	0.717	1	-0.703	1 v 2	0.939
	2	-1.02	2 v 3	<0.001	2	-0.677	2 v 3	<0.001
	3	-1.43	1 v 3	<0.001	3	-1.01	1 v 3	0.001
			1&2 v 3**	<0.001			1&2 v 3**	<0.001
CO_2	1	7.95	1 v 2	0.048	1	8.06	1 v 2	<0.001
	2	8.00	2 v 3	0.963	2	8.26	2 v 3	0.863
	3	7.99	1 v 3	0.085	3	8.28	1 v 3	<0.001
			1 v 2&3***	0.011			1 v 2&3***	<0.001
NH_3	1	-1.39	1 v 2	0.988	1	1.94	1 v 2	0.968
	2	-1.66	2 v 3	0.908	2	2.01	2 v 3	0.865
	3	-0.896	1 v 3	0.960	3	2.16	1 v 3	0.733
H_2S	1	-4.45	1 v 2	0.974	1	-0.969	1 v 2	0.760
	2	-4.18	2 v 3	0.997	2	-0.763	2 v 3	0.996
	3	-4.09	1 v 3	0.955	3	-0.789	1 v 3	0.810
CO	1	0.230	1 v 2	0.744	1	-0.027	1 v 2	0.999
	2	-0.015	2 v 3	0.736	2	-0.012	2 v 3	0.996
	3	-0.264	1 v 3	0.315	3	0.017	1 v 3	0.990

*Mean was computed using the least-square mean of the ln-transformed data (units are ln(mg/m^3) for respirable dust and ln(ppm) for all else).

**Due to the insignificant difference between events one and two, an additional contrast analysis was performed by grouping events one and two and comparing the mean concentrations to event three's mean concentration.

***Due to the insignificant difference between events two and three, an additional contrast analysis was performed by grouping events two and three and comparing the mean concentrations to event one's mean concentration.

Table 6. Comparison of the three 90-minute event means of each contaminant for days when the pit fan was turned off and days when the pit fan was turned on using a nonparametric Kruskal-Wallis test.

		Fan On		Fan Off	
	Event	**Mean Score**	**P**	**Mean Score**	**P**
Dust	1	43.5		28.1	
	2	40.6	<0.001	26.1	<0.001
	3	12.0		10.2	
CO_2	1	11.9		4.62	
	2	22.4	0.027	15.9	0.001
	3	21.2		17.0	
NH_3	1	13.1		8.17	
	2	13.4	0.795	9.00	0.567
	3	15.4		11.3	
H_2S	1	13.6		7.50	
	2	13.9	0.962	10.7	0.529
	3	14.6		10.3	
CO	1	16.7		9.17	
	2	13.7	0.389	9.33	0.960
	3	11.6		10.0	

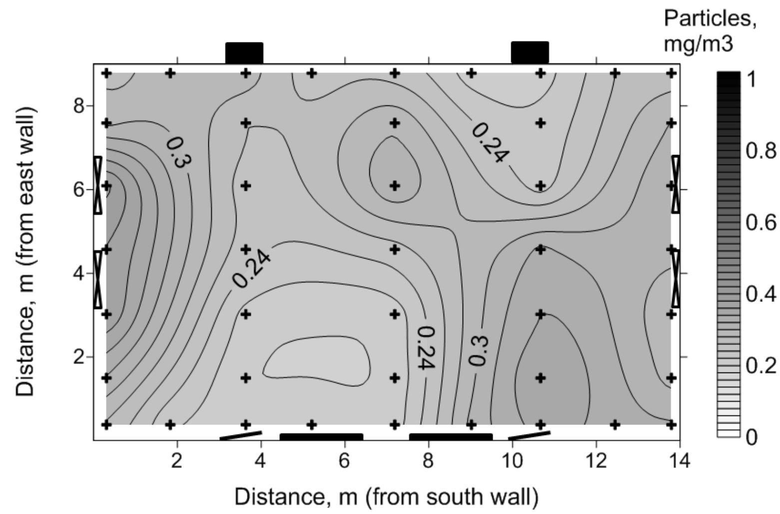

Figure 3. Day 1 contaminant mapping of respirable dust concentrations (pit fan on)

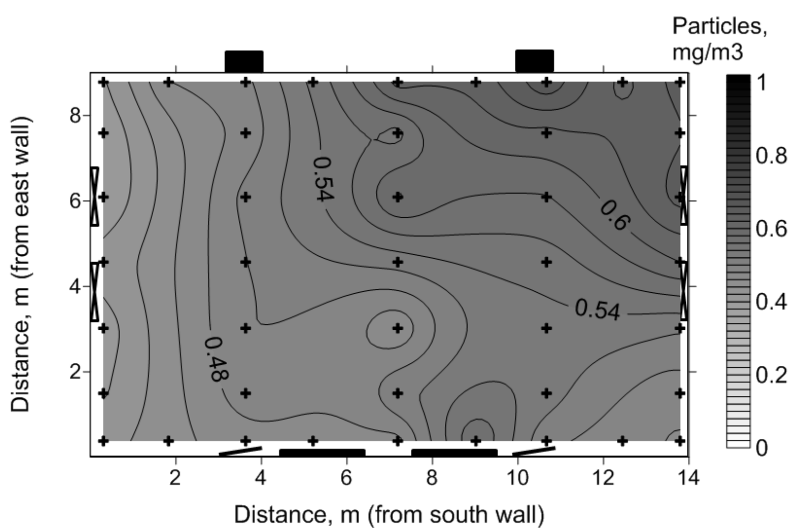

Figure 4. Day 2 contaminant mapping of respirable dust concentrations (pit fan off)

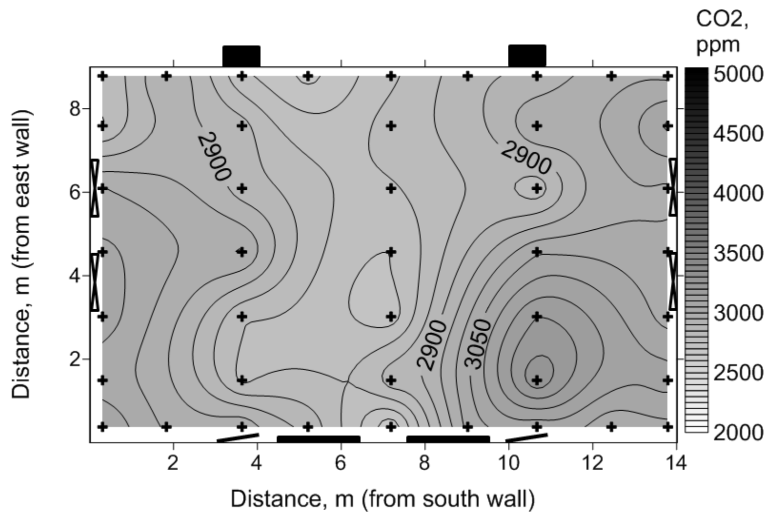

Figure 5. Day 1 contaminant mapping of CO_2 concentrations (pit fan on)

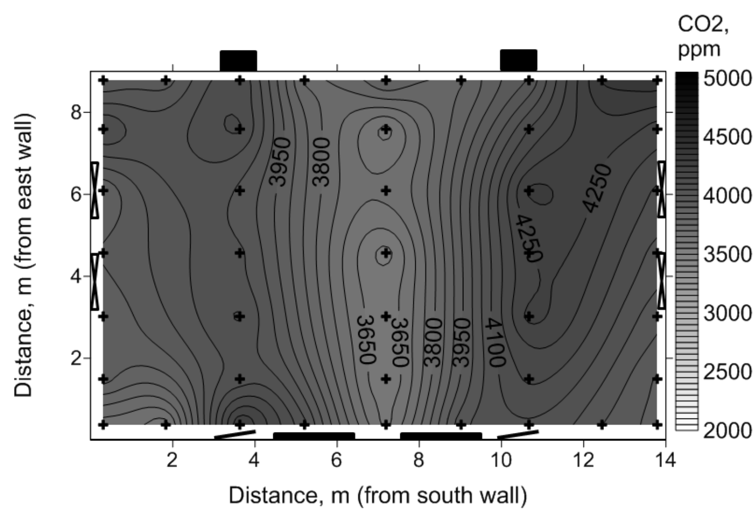

Figure 6. Day 2 contaminant mapping of CO_2 concentrations (pit fan off)

Table 7. Comparison of mean respirable dust concentrations obtained each day using one representative fixed-area station photometer in the middle of the room, seven fixed-area station photometers located throughout the room, and contaminant mapping.

Sample Day (Fan setting)	**One Representative Fixed-Area Station (n=1) Mean (SD) mg/m^3**	**Multiple Fixed-Area Stations (n=7) Mean (SD) mg/m^3**	**Contaminant Mapping (n=43) Mean (SD) mg/m^3**
1 (on)	0.263 (0.110)^{5}	0.296 (0.120)^{5}	0.271 (0.086)^{5}
2 (off)	**0.470** (0.152)^{1}	**0.539** (0.186)^{1}	**0.520** (0.162)^{1}
3 (on)	0.271 (0.091)^{4}	**0.345** (0.134)^{3}	**0.337** (0.127)^{3}
4 (off)	**0.371** (0.113)^{2}	**0.394** (0.116)^{2}	**0.398** (0.116)^{2}
5 (on)	0.287 (0.092)^{3}	**0.340** (0.110)^{4}	0.298 (0.085)^{4}

Superscripted numbers 1-5 represent the rank in dust concentration in descending order for each data collection method. Bolded numbers indicate mean concentrations exceeded the 0.3 mg/m^3 ($^{1}/_{10}$ TLV) criteria.

CHAPTER III

CONCLUSIONS

This study assessed contaminant distribution in a 19-crate farrowing room in winter using fixed-area monitoring and contaminant mapping. In January, respirable dust, CO_2, NH_3, H_2S, and CO concentrations were measured five days over a period of a three-week farrowing cycle. For a daily sample period of five hours, concentration data was gathered from seven fixed-area stations and contaminant mapping that consisted of three sequential 90-minute events collecting two-minute sample concentrations at 43 positions. These measurements were analyzed to determine the change in concentration over the course of a sample day, to evaluate the effect pit ventilation has on contaminant concentration, and to compare data collection methods in the determination of exposure reduction.

Evidence in Chapter II supports the idea that pit ventilation does have an effect on contaminant concentration in a farrowing barn during winter. Mean respirable dust, CO_2, NH_3, and H_2S concentrations were highest when the pit fan was not turned on. In this study, respirable dust concentration increased by 79%, CO_2 concentration increased by 35%, NH_3 concentration increased from 0.03 ppm to 10.8 ppm, and H_2S concentrations increased from 0.03 ppm to 0.67 ppm. A change in mean respirable dust and CO_2 concentrations occurred over the course of the five-hour sample day. Higher respirable dust concentrations were observed in the beginning of the day, both when the pit fan was turned on and off, likely attributed to the feed and swine activity during the morning feeding which occurred between 8:00AM-10:00AM. Area respirable dust concentration decreased 87% by the end of the sample day when the pit fan was turned on and by 77%

when the pit fan was turned on. Without the pit fan turned on there was an increase in CO_2 concentration, by 24%, that is likely due to the inefficient ventilation and the constant production of CO_2 generated by the swine. Contaminant concentration did not exceed regulatory or consensus standards throughout the course of the study, however, recommended agricultural limits suggested in the literature were surpassed for respirable dust, CO_2, and NH_3. Comparing the three data collection methods produced similar results concerning the ranking of the daily mean concentrations of respirable dust; however, differences were seen in the magnitude of the daily average respirable dust concentrations across the three data collection methods. The most conservative method that generated the highest concentrations was the application of seven fixed-area monitors that collected concentration measurements over the five-hour sample period. The difference in the daily respirable dust concentrations generated by the three data collection methods suggested that the approach chosen may result in an over- or underestimation of worker area exposure.

Future research is needed to strengthen the assessment of contaminant distribution in a farrowing barn during winter with low ventilation rates. Due to the increase in CO_2 concentrations over the course of a sample period, it should be considered to monitor an entire work shift to determine if concentrations do increase further and possibly surpass the limit for worker exposure. Both similarities and differences were observed in the test site and the production facilities. Gaining a clear understanding of the layout and operation of a representative farrowing facility is essential in comparing results across studies and for the creation and application of control techniques. Area monitoring using direct-reading equipment was the focus of this study so looking at personal worker exposure under the same conditions will provide exposure estimates that workers are personally being exposed to while performing tasks in farrowing facilities. Due to the limited time workers spent in the one farrowing unit at the test site, there is little concern in the worker's full shift, or time-weighted average, exposure. Personal worker exposure at the test site did not reflect work patterns in production. Production workers spent a full shift working in multiple farrowing units, therefore performing more tasks at an increased rate which increased exposure to contaminants in the farrowing units. Despite its limitations, the results of this study are important and can be applied to direct the focus of future studies in this field.

APPENDIX A: INSTRUMENT COLLOCATION ANALYSIS AND RESULTING ADJUSTMENT FACTORS

Throughout the five day sample period both mapping and fixed area instruments were collocated at the beginning of the day before being deployed in the designated fixed area stations and mapping began. Collocating the instruments allowed the determination if all of the different instruments were measuring similar concentrations.

The photometers were collocated in the hallway directly outside of the farrowing room on day one through day five. After the pumps accompanying the photometers warmed up, running approximately five minutes, the photometers were zeroed with a zero air filter. After passing the calibration test the photometers ran five minutes with the zero air filters on and five minutes with the zero air filters off. At the end of the sample day the photometers were collocated in the hallway running approximately five minutes with the zero air filters off.

The air velocity meters and the multi-gas meters were collocated in the hallway prior to being deployed for sampling on day three through day five, logging hallway concentrations for approximately ten minutes. At the end of the sample day the air velocity meters were collocated in the middle of the farrowing room and the multi-gas meters were collocated in the hallway, running approximately five minutes.

The photometers and air velocity meters measurements were adjusted using each day's adjustment factors. With the exception of day five, the multi-gas meters did not need to be adjusted. Linear regression was used to determine the fit of each instrument's measurements to the average concentration of all of the instruments. To adjust the measurements, the slope from the linear regression was used along with a zero-intercept with the exception of the multi-gas meters which were adjusted using a slope and intercept from the linear regression equation. R^2 is included to show that the model relating the instruments' measurements (y) to the average of all of them (x) can explain the variation in the measurements to a certain extent (%).

Table A- 1. Results of the linear regression performed for each photometer on each sample day

Photometer	Day 1	Day 2	Day 3	Day 4	Day 5
	Slope (R^2)	Slope (R^2)	Slope (R^2)	Slope (R^2)	Slope (R^2)
A	0.951 (0.98)	0.973 (0.97)	0.914 (0.93)	0.956 (0.95)	1.07 (0.95)
B	0.936 (0.99)	0.997 (0.96)	0.897 (0.95)	0.927 (0.98)	0.962 (0.97)
C	1.07 (0.99)	1.07 (0.97)	1.18 (0.90)	1.11 (0.94)	1.08 (0.91)
D	0.993 (0.99)	0.963 (0.98)	0.724 (0.74)*	1.03 (0.97)	0.934 (0.95)
E	1.04 (0.99)	0.992 (0.98)	0.966 (0.93)	0.902 (0.93)	0.866 (0.95)
F	0.959 (0.99)	0.938 (0.99)	0.937 (0.95)	0.914 (0.99)	0.996 (0.97)
G	1.03 (0.99)	0.992 (0.98)	0.950 (0.79)	1.00 (0.98)	1.05 (0.93)
Mapping	1.13 (0.97)	1.15 (0.94)	1.21 (0.98)	1.23 (0.98)	1.05 (0.96)

*Due to the lack of fit of the regression using a zero-intercept the intercept in the linear regression was used

Table A- 2. Results of the linear regression performed for each air velocity meter on sample days one through three.

Air Velocity Meter	Day 3	Day 4	Day 5
	Slope (R^2)	Slope (R^2)	Slope (R^2)
A	0.991 (0.99)	0.996 (0.99)	1.01 (0.99)
C	0.981 (0.99)	0.980 (0.99)	0.998 (0.99)
E	1.02 (0.78)	1.02 (0.99)	0.992 (0.99)
G	0.943 (0.93)	1.01 (0.98)	1.00 (0.99)
Mapping	1.02 (0.99)	0.987 (0.98)	1.00 (0.99)

Table A- 3. Results of the linear regression performed for each multi-gas meter on sample day five.

Multi-gas Meter	Day 5	
	Slope (R^2)	Intercept
B	1.23 (0.99)	0.15
C	1.00 (0.99)	-0.92
F	0.832 (0.99)	0.72

APPENDIX B: DISTRIBUTION ANALYSIS

The normality of the data's distribution was analyzed using the statistical package SAS (Version 9.2, SAS Institute Inc., Cary, NC, USA) prior to performing statistical tests for objectives one and two. Both the arithmetic means and the ln-transformed values were analyzed using the Shapiro-Wilk test. Results with a $p<0.05$ were interpreted as not following a normal distribution. Two separate tests were run using the two data sets that were applied to objectives one and two.

Table B- 1. Results of Shapiro-Wilk test corresponding with objective one (data were not considered normally distributed with $p<0.05$).

Data	No Transformation		LN-Transformation	
	W-Statistic	P	W-Statistic	P
Dust-Off	0.884	0.001	0.926	0.010
Dust-On	0.973	0.177	0.963	0.056
CO_2-Off	0.950	0.278	0.946	0.224
CO_2-On	0.962	0.248	0.970	0.414
NH_3-Off	0.881	0.028	0.778	0.001
NH_3-On	0.698	0.000	0.813	0.000
H_2S-Off	0.885	0.032	0.900	0.057
H_2S-On	0.745	0.000	0.815	0.000
CO-Off	0.856	0.010	0.822	0.003
CO-On	0.988	0.984	0.808	0.000

Table B- 2. Results of Shapiro-Wilk test corresponding with objective two (data were not considered normally distributed with $p<0.05$).

Data	No Transformation		LN-Transformation	
	W-Statistic	P	W-Statistic	P
Dust-Off-Pass 1	0.935	0.362	0.952	0.594
Dust-Off-Pass 2	0.853	0.025	0.852	0.023
Dust-Off-Pass 3	0.957	0.672	0.955	0.638
Dust-On-Pass 1	0.958	0.469	0.971	0.766
Dust-On-Pass 2	0.969	0.722	0.968	0.678
Dust-On-Pass 3	0.922	0.098	0.946	0.284
CO_2-Off-Pass 1	0.964	0.847	0.959	0.804
CO_2-Off-Pass 2	0.986	0.986	0.983	0.978
CO_2-Off-Pass 3	0.960	0.806	0.954	0.751
CO_2-On-Pass 1	0.971	0.919	0.971	0.924
CO_2-On-Pass 2	0.961	0.800	0.962	0.808
CO_2-On-Pass 3	0.946	0.577	0.956	0.722
NH_3-Off-Pass 1	0.975	0.922	0.876	0.252
NH_3-Off-Pass 2	0.836	0.122	0.721	0.010
NH_3-Off-Pass 3	0.843	0.138	0.755	0.022
NH_3-On-Pass 1	0.711	0.002	0.842	0.062
NH_3-On-Pass 2	0.694	0.001	0.832	0.046
NH_3-On-Pass 3	0.719	0.002	0.817	0.032
H_2S-Off-Pass 1	0.929	0.576	0.939	0.648
H_2S-Off-Pass 2	0.909	0.428	0.914	0.460
H_2S-Off-Pass 3	0.849	0.155	0.855	0.172
H_2S-On-Pass 1	0.718	0.002	0.855	0.085
H_2S-On-Pass 2	0.771	0.009	0.853	0.081
H_2S-On-Pass 3	0.780	0.012	0.786	0.014
CO-Off-Pass 1	0.922	0.520	0.907	0.415
CO-Off-Pass 2	0.853	0.167	0.814	0.079
CO-Off-Pass 3	0.867	0.215	0.822	0.092
CO-On-Pass 1	0.958	0.782	0.965	0.847
CO-On-Pass 2	0.979	0.962	0.950	0.691
CO-On-Pass 3	0.972	0.911	0.767	0.009

APPENDIX C: DATA ANALYSIS RESULTS

Data were analyzed using the statistical package SAS (Version 9.2, SAS Institute Inc., Cary, NC, USA). The statistical tests were evaluated at the 95% confidence level. Objective one involves comparing the contaminant concentrations over days when the manure pit fan was off to the days when it was on. Objective two was to determine the change in concentration over time throughout the course of a sample day which involves a comparison of the ln-transformed average concentrations of the three 90-minute events. Due to the normality of the distribution, the data for the days with the manure pit fan off and on were analyzed separately. Analysis was done using an average of both the arithmetic and the ln-transformed means of the three 90-minute sample events. Due to an unbalanced design a general linear model procedure was used along with lsmeans which produced least-square, adjusted means for the main effects. An adjusted Tukey, or Tukey-Kramer, method was used in the post-hoc analysis for objectives one and two. In addition, to make specific comparisons of the ln-transformed means of the three events to determine the change in concentration over time throughout the course of a sample day, contrasts, or planned comparisons were analyzed.

In addition to the general linear model procedure, nonparametric statistics were performed on the data. A Wilcoxon Two-Sample test was performed to analyze the data for objective one. A $p<0.05$ indicated that the pit fan setting, on compared to off, accounted for a significant portion of the variability in the contaminant concentration. To analyze the data for objective two a Kruskal-Wallis test was performed. A $p<0.05$ indicated that there is evidence to suggest that at least one of the 90-minute event medians differed from each other.

Hypothesis1: Concentration Change Over Time

Throughout the Course of a Sample Day

Parametric Statistics

Dust: Pit Fan On

PROC GLM Data=ONdustsasC;
Title 'Analysis of dust concentrations over the course of a day W/ pit fan on- comparison of pass 1, 2, 3';
Class day pass setting station;
Model LNdustr=pass;
lsmeans pass/pdiff adjust=tukey;
contrast '1 VS 2' pass **-1 1 0**;
contrast '2 vs 3' pass **0 1 -1**;
contrast '1 vs 3' pass **-1 0 1**;
contrast '1&2 vs 3' pass **1 1 -2**;
CONTRAST '1 VS 2&3' PASS -**2 1 1**;
CONTRAST '2 VS 1&3' PASS -**2 1 1**;
run;

```
Analysis of dust concentrations over the course of a day W/ pit fan on- comparison of
pass  130
                                             09:19 Wednesday, March 7, 2012

                                       The GLM Procedure

                                    Class Level Information

                             Class         Levels    Values

                             Day                3    1 3 5

                             Pass               3    1 2 3

                             Setting            1    on

                             Station            7    A B C D E F G


                             Number of Observations Read          63
                             Number of Observations Used          63
```

Analysis of dust concentrations over the course of a day W/ pit fan on- comparison of pass 131

09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: LnDustR LnDustR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2.60398295	1.30199148	54.54	<.0001
Error	60	1.43220848	0.02387014		
Corrected Total	62	4.03619143			

R-Square	Coeff Var	Root MSE	LnDustR Mean
0.645158	-13.50803	0.154500	-1.143762

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Pass	2	2.60398295	1.30199148	54.54	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Pass	2	2.60398295	1.30199148	54.54	<.0001

Analysis of dust concentrations over the course of a day W/ pit fan on- comparison of pass 132

09:19 Wednesday, March 7, 2012

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Pass	LnDustR LSMEAN	LSMEAN Number
1	-0.98180952	1
2	-1.01900000	2
3	-1.43047619	3

Least Squares Means for effect Pass
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: LnDustR

i/j	1	2	3
1		0.7167	<.0001
2	0.7167		<.0001
3	<.0001	<.0001	

Analysis of dust concentrations over the course of a day W/ pit fan on- comparison of pass 137

09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: LnDustR LnDustR

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1 VS 2	1	0.01452288	0.01452288	0.61	0.4385
2 vs 3	1	1.77778288	1.77778288	74.48	<.0001
1 vs 3	1	2.11366867	2.11366867	88.55	<.0001
1&2 vs 3	1	2.58946007	2.58946007	108.48	<.0001
1 VS 2&3	1	0.82620007	0.82620007	34.61	<.0001
2 VS 1&3	1	0.82620007	0.82620007	34.61	<.0001

Dust: Pit Fan Off

```
PROC GLM Data=OffdustsasC;
Title 'Analysis of dust concentrations over the course of a day W/ pit fan off- comparison of pass 1, 2, 3';
Class day pass setting station;
Model LNdustr=pass;
lsmeans pass/pdiff adjust=tukey;
contrast '1 VS 2' pass -1 1 0;
contrast '2 vs 3' pass 0 1 -1;
contrast '1 vs 3' pass -1 0 1;
contrast '1&2 vs 3' pass 1 1 -2;
CONTRAST '1 VS 2&3' PASS -2 1 1;
CONTRAST '2 VS 1&3' PASS -2 1 1;
run;
```

Analysis of dust concentrations over the course of a day W/ pit fan off- comparison of pass 138

09:19 Wednesday, March 7, 2012

The GLM Procedure

Class Level Information

Class	Levels	Values
Day	2	2 4
Pass	3	1 2 3
Setting	1	off
Station	7	A B C D E F G

Number of Observations Read 42
Number of Observations Used 42

Analysis of dust concentrations over the course of a day W/ pit fan off- comparison of pass 139

09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: LnDustR LnDustR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.97188376	0.48594188	11.50	0.0001
Error	39	1.64813586	0.04225989		
Corrected Total	41	2.62001962			

R-Square	Coeff Var	Root MSE	LnDustR Mean
0.370945	-25.79632	0.205572	-0.796905

Source	DF	Type I SS	Mean Square	F Value	Pr > F

Pass	2	0.97188376	0.48594188	11.50	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Pass	2	0.97188376	0.48594188	11.50	0.0001

Analysis of dust concentrations over the course of a day W/ pit fan off- comparison of pass 140

09:19 Wednesday, March 7, 2012

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Pass	LnDustR LSMEAN	LSMEAN Number
1	-0.70271429	1
2	-0.67650000	2
3	-1.01150000	3

Least Squares Means for effect Pass
Pr > |t| for H0: LSMean(i)=LSMean(j)
Dependent Variable: LnDustR

i/j	1	2	3
1		0.9393	0.0008
2	0.9393		0.0003
3	0.0008	0.0003	

Analysis of dust concentrations over the course of a day W/ pit fan off- comparison of pass 141

09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: LnDustR LnDustR

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1 VS 2	1	0.00481032	0.00481032	0.11	0.7376
2 vs 3	1	0.78557500	0.78557500	18.59	0.0001
1 vs 3	1	0.66744032	0.66744032	15.79	0.0003
1&2 vs 3	1	0.96707344	0.96707344	22.88	<.0001
1 VS 2&3	1	0.18630876	0.18630876	4.41	0.0423
2 VS 1&3	1	0.18630876	0.18630876	4.41	0.0423

CO_2: Pit Fan On

PROC GLM Data=Onco2sasC;
Title 'Analysis of co2 concentrations over the course of a day W/ pit fan on- comparison of pass 1, 2, 3';
Class day pass setting station;
Model LNco2r=pass;
lsmeans pass/pdiff adjust=tukey;
contrast '1 VS 2' pass **-1 1 0**;
contrast '2 vs 3' pass **0 1 -1**;
contrast '1 vs 3' pass **-1 0 1**;
contrast '1&2 vs 3' pass **1 1 -2**;
CONTRAST '1 VS 2&3' PASS **-2 1 1**;
CONTRAST '2 VS 1&3' PASS **-2 1 1**;
run;

Analysis of co2 concentrations over the course of a day W/ pit fan on- comparison of pass 1 146

09:19 Wednesday, March 7, 2012

The GLM Procedure

Class Level Information

Class	Levels	Values
Day	3	1 3 5
Pass	3	1 2 3
Setting	1	on
Station	4	A C E G

Number of Observations Read 36
Number of Observations Used 36

Analysis of co2 concentrations over the course of a day W/ pit fan on- comparison of pass 1 147

09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: LnCO2R LnCO2R

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.01925906	0.00962953	3.68	0.0360
Error	33	0.08627525	0.00261440		
Corrected Total	35	0.10553431			

R-Square	Coeff Var	Root MSE	LnCO2R Mean
0.182491	0.640611	0.051131	7.981639

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Pass	2	0.01925906	0.00962953	3.68	0.0360

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Pass	2	0.01925906	0.00962953	3.68	0.0360

Analysis of co2 concentrations over the course of a day W/ pit fan on- comparison of pass 1 148

09:19 Wednesday, March 7, 2012

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Pass	LnCO2R LSMEAN	LSMEAN Number
1	7.94908333	1
2	8.00066667	2
3	7.99516667	3

Least Squares Means for effect Pass
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: LnCO2R

i/j	1	2	3
1		0.0481	0.0847
2	0.0481		0.9625
3	0.0847	0.9625	

Analysis of co2 concentrations over the course of a day W/ pit fan on- comparison of pass 1 149

09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: LnCO2R LnCO2R

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1 VS 2	1	0.01596504	0.01596504	6.11	0.0188
2 vs 3	1	0.00018150	0.00018150	0.07	0.7938
1 vs 3	1	0.01274204	0.01274204	4.87	0.0343
1&2 vs 3	1	0.00329401	0.00329401	1.26	0.2698
1 VS 2&3	1	0.01907756	0.01907756	7.30	0.0108
2 VS 1&3	1	0.01907756	0.01907756	7.30	0.0108

CO_2: Pit Fan Off

PROC GLM Data=Offco2sasC;
Title 'Analysis of co2 concentrations over the course of a day W/ pit fan off- comparison of pass 1, 2, 3';
Class day pass setting station;
Model LNco2r=pass;
lsmeans pass/pdiff adjust=tukey;
contrast '1 VS 2' pass **-1 1 0**;
contrast '2 vs 3' pass **0 1 -1**;
contrast '1 vs 3' pass **-1 0 1**;
contrast '1&2 vs 3' pass **1 1 -2**;
CONTRAST '1 VS 2&3' PASS **-2 1 1**;
CONTRAST '2 VS 1&3' PASS **-2 1 1**;
run;

Analysis of co2 concentrations over the course of a day W/ pit fan off- comparison of pass 150

09:19 Wednesday, March 7, 2012

The GLM Procedure

Class Level Information

Class	Levels	Values
Day	2	2 4
Pass	3	1 2 3
Setting	1	off
Station	4	A C E G

Number of Observations Read 24
Number of Observations Used 24

Analysis of co2 concentrations over the course of a day W/ pit fan off- comparison of pass 151

09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: LnCO2R LnCO2R

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.22237808	0.11118904	27.11	<.0001
Error	21	0.08612125	0.00410101		
Corrected Total	23	0.30849933			

R-Square	Coeff Var	Root MSE	LnCO2R Mean
0.720838	0.781045	0.064039	8.199167

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Pass	2	0.22237808	0.11118904	27.11	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Pass	2	0.22237808	0.11118904	27.11	<.0001

Analysis of co2 concentrations over the course of a day W/ pit fan off- comparison of pass 152

09:19 Wednesday, March 7, 2012

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Pass	LnCO2R LSMEAN	LSMEAN Number
1	8.06337500	1
2	8.25875000	2
3	8.27537500	3

Least Squares Means for effect Pass
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: LnCO2R

i/j	1	2	3
1		<.0001	<.0001
2	<.0001		0.8629
3	<.0001	0.8629	

Analysis of co2 concentrations over the course of a day W/ pit fan off- comparison of pass 153

09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: LnCO2R LnCO2R

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1 VS 2	1	0.15268556	0.15268556	37.23	<.0001
2 vs 3	1	0.00110556	0.00110556	0.27	0.6090
1 vs 3	1	0.17977600	0.17977600	43.84	<.0001
1&2 vs 3	1	0.06969252	0.06969252	16.99	0.0005
1 VS 2&3	1	0.22127252	0.22127252	53.96	<.0001
2 VS 1&3	1	0.22127252	0.22127252	53.96	<.0001

NH_3: Pit Fan On

```
PROC GLM Data=ONNH3sasC;
Title 'Analysis of NH3 concentrations over the course of a day W/ pit fan ON-
comparison of pass 1, 2, 3';
Class day pass setting station;
Model LNNH3r=pass;
lsmeans pass/pdiff adjust=tukey;
contrast '1 VS 2' pass -1 1 0;
contrast '2 vs 3' pass 0 1 -1;
contrast '1 vs 3' pass -1 0 1;
contrast '1&2 vs 3' pass 1 1 -2;
CONTRAST '1 VS 2&3' PASS -2 1 1;
CONTRAST '2 VS 1&3' PASS -2 1 1;
run;
```

```
Analysis of NH3 concentrations over the course of a day W/ pit fan ON- comparison of pass
1,  1
                                                    15:00 Friday, March 9, 2012
                                       The GLM Procedure
                                   Class Level Information

                                Class         Levels    Values

                                Day                3    1 3 5

                                Pass               3    1 2 3

                                Setting            1    on

                                Station            3    B C F

                            Number of Observations Read          27
                            Number of Observations Used          27
```

```
Analysis of NH3 concentrations over the course of a day W/ pit fan ON- comparison of pass
1,  2
                                                    15:00 Friday, March 9, 2012
                                       The GLM Procedure
Dependent Variable: LNNH3R   LNNH3R

                                               Sum of
      Source                      DF          Squares     Mean Square    F Value    Pr > F

      Model                        2        2.7187632       1.3593816       0.09    0.9137

      Error                       24      359.9289611      14.9970400

      Corrected Total             26      362.6477243

                      R-Square     Coeff Var      Root MSE    LNNH3R Mean

                      0.007497     -293.9645      3.872601      -1.317370

      Source                      DF        Type I SS     Mean Square    F Value    Pr > F

      Pass                         2       2.71876319      1.35938159       0.09    0.9137


      Source                      DF      Type III SS     Mean Square    F Value    Pr > F

      Pass                         2       2.71876319      1.35938159       0.09    0.9137
```

```
Analysis of NH3 concentrations over the course of a day W/ pit fan ON- comparison of pass
1,  3
                                                     15:00 Friday, March 9, 2012
                                      The GLM Procedure
                                     Least Squares Means
                         Adjustment for Multiple Comparisons: Tukey
                                            LNNH3R      LSMEAN
                              Pass          LSMEAN      Number

                              1        -1.39466667           1
                              2        -1.66155556           2
                              3        -0.89588889           3

                           Least Squares Means for effect Pass
                           Pr > |t| for H0: LSMean(i)=LSMean(j)

                                Dependent Variable: LNNH3R

                       i/j              1             2             3

                          1                        0.9883        0.9598
                          2        0.9883                        0.9080
                          3        0.9598        0.9080
```

```
Analysis of NH3 concentrations over the course of a day W/ pit fan ON- comparison of pass
1,  4
                                         15:00 Friday, March 9, 2012
                                      The GLM Procedure
Dependent Variable: LNNH3R   LNNH3R
```

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1 VS 2	1	0.32053356	0.32053356	0.02	0.8850
2 vs 3	1	2.63810450	2.63810450	0.18	0.6786
1 vs 3	1	1.11950672	1.11950672	0.07	0.7870
1&2 vs 3	1	2.39822963	2.39822963	0.16	0.6928
1 VS 2&3	1	0.08065869	0.08065869	0.01	0.9421
2 VS 1&3	1	0.08065869	0.08065869	0.01	0.9421

NH_3: Pit Fan Off

PROC GLM Data=OFFNH3sasC;
Title 'Analysis of NH3 concentrations over the course of a day W/ pit fan OFF- comparison of pass 1, 2, 3';
Class day pass setting station;
Model LNNH3r=pass;
lsmeans pass/pdiff adjust=tukey;
contrast '1 VS 2' pass **-1 1 0**;
contrast '2 vs 3' pass **0 1 -1**;
contrast '1 vs 3' pass **-1 0 1**;
contrast '1&2 vs 3' pass **1 1 -2**;
CONTRAST '1 VS 2&3' PASS -**2 1 1**;
CONTRAST '2 VS 1&3' PASS -**2 1 1**;
run;

```
Analysis of NH3 concentrations over the course of a day W/ pit fan OFF- comparison of
pass  158
                                                 09:19 Wednesday, March 7, 2012

                                      The GLM Procedure
```

Class Level Information

Class	Levels	Values
Day	2	2 4
Pass	3	1 2 3
Setting	1	off
Station	3	B C F

Number of Observations Read	18
Number of Observations Used	18

The GLM Procedure

Dependent Variable: LNNH3R LNNH3R

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.14594844	0.07297422	0.30	0.7449
Error	15	3.64467667	0.24297844		
Corrected Total	17	3.79062511			

R-Square	Coeff Var	Root MSE	LNNH3R Mean
0.038502	24.17764	0.492928	2.038778

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Pass	2	0.14594844	0.07297422	0.30	0.7449

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Pass	2	0.14594844	0.07297422	0.30	0.7449

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Pass	LNNH3R LSMEAN	LSMEAN Number
1	1.94366667	1
2	2.01300000	2
3	2.15966667	3

Least Squares Means for effect Pass
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: LNNH3R

i/j	1	2	3
1		0.9679	0.7330
2	0.9679		0.8651
3	0.7330	0.8651	

09:19 Wednesday, March 7, 2012
The GLM Procedure

Dependent Variable: LNNH3R LNNH3R

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1 VS 2	1	0.01442133	0.01442133	0.06	0.8108
2 vs 3	1	0.06453333	0.06453333	0.27	0.6138
1 vs 3	1	0.13996800	0.13996800	0.58	0.4596
1&2 vs 3	1	0.13152711	0.13152711	0.54	0.4732
1 VS 2&3	1	0.08141511	0.08141511	0.34	0.5713
2 VS 1&3	1	0.08141511	0.08141511	0.34	0.5713

H_2S: Pit Fan On

PROC GLM Data=ONH2SsasC;
Title 'Analysis of H2S concentrations over the course of a day W/ pit fan ON-comparison of pass 1, 2, 3';
Class day pass setting station;
Model LNH2Sr=pass;
lsmeans pass/pdiff adjust=tukey;
contrast '1 VS 2' pass **-1 1 0**;
contrast '2 vs 3' pass **0 1 -1**;
contrast '1 vs 3' pass **-1 0 1**;
contrast '1&2 vs 3' pass **1 1 -2**;
CONTRAST '1 VS 2&3' PASS -**2 1 1**;
CONTRAST '2 VS 1&3' PASS -**2 1 1**;
run;

Analysis of H2S concentrations over the course of a day W/ pit fan ON- comparison of pass 1, 5
15:00 Friday, March 9, 2012
The GLM Procedure
Class Level Information

Class	Levels	Values
Day	3	1 3 5
Pass	3	1 2 3
Setting	1	on
Station	3	B C F

Number of Observations Read	27
Number of Observations Used	27

Analysis of H2S concentrations over the course of a day W/ pit fan ON- comparison of pass 1, 6
15:00 Friday, March 9, 2012
The GLM Procedure
Dependent Variable: LNH2SR LNH2SR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.6419309	0.3209654	0.05	0.9559

Error	24	170.4012558	7.1000523		
Corrected Total	26	171.0431867			

R-Square	Coeff Var	Root MSE	LNH2SR Mean
0.003753	-62.82276	2.664592	-4.241444

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Pass	2	0.64193089	0.32096544	0.05	0.9559

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Pass	2	0.64193089	0.32096544	0.05	0.9559

Analysis of H2S concentrations over the course of a day W/ pit fan ON- comparison of pass 1, 7
15:00 Friday, March 9, 2012
The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Pass	LNH2SR LSMEAN	LSMEAN Number
1	-4.45333333	1
2	-4.18011111	2
3	-4.09088889	3

Least Squares Means for effect Pass
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: LNH2SR

i/j	1	2	3
1		0.9743	0.9552
2	0.9743		0.9972
3	0.9552	0.9972	

Analysis of H2S concentrations over the course of a day W/ pit fan ON- comparison of pass 1, 8
15:00 Friday, March 9, 2012
The GLM Procedure

Dependent Variable: LNH2SR LNH2SR

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1 VS 2	1	0.33592672	0.33592672	0.05	0.8296
2 vs 3	1	0.03582272	0.03582272	0.01	0.9440
1 vs 3	1	0.59114689	0.59114689	0.08	0.7754
1&2 vs 3	1	0.30600417	0.30600417	0.04	0.8373
1 VS 2&3	1	0.60610817	0.60610817	0.09	0.7727
2 VS 1&3	1	0.60610817	0.60610817	0.09	0.7727

H_2S: Pit Fan Off

PROC GLM Data=OFFH2SsasC;
Title 'Analysis of H2S concentrations over the course of a day W/ pit fan OFF-comparison of pass 1, 2, 3';
Class day pass setting station;
Model LNH2Sr=pass;

lsmeans pass/pdiff adjust=tukey;
contrast '1 VS 2' pass **-1 1 0**;
contrast '2 vs 3' pass **0 1 -1**;
contrast '1 vs 3' pass **-1 0 1**;
contrast '1&2 vs 3' pass **1 1 -2**;
CONTRAST '1 VS 2&3' PASS **-2 1 1**;
CONTRAST '2 VS 1&3' PASS **-2 1 1**;
run;

Analysis of H2S concentrations over the course of a day W/ pit fan OFF- comparison of pass 166

09:19 Wednesday, March 7, 2012

The GLM Procedure

Class Level Information

Class	Levels	Values
Day	2	2 4
Pass	3	1 2 3
Setting	1	off
Station	3	B C F

Number of Observations Read	18
Number of Observations Used	18

Analysis of H2S concentrations over the course of a day W/ pit fan OFF- comparison of pass 167

09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: LNH2SR LNH2SR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.15153911	0.07576956	0.30	0.7441
Error	15	3.76979067	0.25131938		
Corrected Total	17	3.92132978			

R-Square	Coeff Var	Root MSE	LNH2SR Mean
0.038645	-59.67278	0.501318	-0.840111

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Pass	2	0.15153911	0.07576956	0.30	0.7441

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Pass	2	0.15153911	0.07576956	0.30	0.7441

Analysis of H2S concentrations over the course of a day W/ pit fan OFF- comparison of pass 168

09:19 Wednesday, March 7, 2012

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Pass	LNH2SR LSMEAN	LSMEAN Number

1	-0.96900000	1
2	-0.76266667	2
3	-0.78866667	3

Least Squares Means for effect Pass
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: LNH2SR

i/j	1	2	3
1		0.7598	0.8099
2	0.7598		0.9956
3	0.8099	0.9956	

Analysis of H2S concentrations over the course of a day W/ pit fan OFF- comparison of pass 169
09:19 Wednesday, March 7, 2012
The GLM Procedure

Dependent Variable: LNH2SR LNH2SR

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1 VS 2	1	0.12772033	0.12772033	0.51	0.4869
2 vs 3	1	0.00202800	0.00202800	0.01	0.9296
1 vs 3	1	0.09756033	0.09756033	0.39	0.5426
1&2 vs 3	1	0.02381878	0.02381878	0.09	0.7624
1 VS 2&3	1	0.14951111	0.14951111	0.59	0.4525
2 VS 1&3	1	0.14951111	0.14951111	0.59	0.4525

CO: Pit Fan On

PROC GLM Data=ONCOsasC;
Title 'Analysis of CO concentrations over the course of a day W/ pit fan ON- comparison of pass 1, 2, 3';
Class day pass setting station;
Model LNCOr=pass;
lsmeans pass/pdiff adjust=tukey;
contrast '1 VS 2' pass **-1 1 0**;
contrast '2 vs 3' pass **0 1 -1**;
contrast '1 vs 3' pass **-1 0 1**;
contrast '1&2 vs 3' pass **1 1 -2**;
CONTRAST '1 VS 2&3' PASS -**2 1 1**;
CONTRAST '2 VS 1&3' PASS -**2 1 1**;
run;

Analysis of CO concentrations over the course of a day W/ pit fan ON- comparison of pass 1, 170
09:19 Wednesday, March 7, 2012

The GLM Procedure

Class Level Information

Class	Levels	Values
Day	3	1 3 5
Pass	3	1 2 3

Setting	1	on
Station	3	B C F

Number of Observations Read	27
Number of Observations Used	27

The GLM Procedure

Dependent Variable: LNCOR LNCOR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1.09868719	0.54934359	1.11	0.3472
Error	24	11.92335133	0.49680631		
Corrected Total	26	13.02203852			

R-Square	Coeff Var	Root MSE	LNCOR Mean
0.084371	-4295.894	0.704845	-0.016407

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Pass	2	1.09868719	0.54934359	1.11	0.3472

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Pass	2	1.09868719	0.54934359	1.11	0.3472

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Pass	LNCOR LSMEAN	LSMEAN Number
1	0.22988889	1
2	-0.01488889	2
3	-0.26422222	3

Least Squares Means for effect Pass
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: LNCOR

i/j	1	2	3
1		0.7444	0.3147
2	0.7444		0.7363
3	0.3147	0.7363	

The GLM Procedure

Dependent Variable: LNCOR LNCOR

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1 VS 2	1	0.26962272	0.26962272	0.54	0.4685
2 vs 3	1	0.27975200	0.27975200	0.56	0.4603
1 vs 3	1	1.09865606	1.09865606	2.21	0.1500

1&2 vs 3	1	0.82906446	0.82906446	1.67	0.2087
1 VS 2&3	1	0.81893519	0.81893519	1.65	0.2114
2 VS 1&3	1	0.81893519	0.81893519	1.65	0.2114

CO: Pit Fan Off

PROC GLM Data=OFFCOsasC;
Title 'Analysis of CO concentrations over the course of a day W/ pit fan OFF- comparison of pass 1, 2, 3';
Class day pass setting station;
Model LNCOr=pass;
lsmeans pass/pdiff adjust=tukey;
contrast '1 VS 2' pass **-1 1 0**;
contrast '2 vs 3' pass **0 1 -1**;
contrast '1 vs 3' pass **-1 0 1**;
contrast '1&2 vs 3' pass **1 1 -2**;
CONTRAST '1 VS 2&3' PASS **-2 1 1**;
CONTRAST '2 VS 1&3' PASS **-2 1 1**;
run;

```
Analysis of CO concentrations over the course of a day W/ pit fan OFF- comparison of pass
1 174
                                                    09:19 Wednesday, March 7, 2012

                                      The GLM Procedure

                                  Class Level Information

                               Class         Levels    Values

                               Day                2    2 4

                               Pass               3    1 2 3

                               Setting            1    off

                               Station            3    B C F


                           Number of Observations Read          18
                           Number of Observations Used          18
```

```
Analysis of CO concentrations over the course of a day W/ pit fan OFF- comparison of pass
1 175
                                                 09:19 Wednesday, March 7, 2012
                                      The GLM Procedure
Dependent Variable: LNCOR   LNCOR
                                             Sum of
      Source                      DF        Squares     Mean Square    F Value    Pr > F

      Model                        2     0.00583878      0.00291939       0.01    0.9907

      Error                       15     4.68105433      0.31207029

      Corrected Total             17     4.68689311

                      R-Square     Coeff Var      Root MSE    LNCOR Mean

                      0.001246     -7734.912      0.558633     -0.007222

      Source                      DF      Type I SS     Mean Square    F Value    Pr > F
```

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Pass	2	0.00583878	0.00291939	0.01	0.9907

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Pass	2	0.00583878	0.00291939	0.01	0.9907

Analysis of CO concentrations over the course of a day W/ pit fan OFF- comparison of pass 1 176
09:19 Wednesday, March 7, 2012

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Pass	LNCOR LSMEAN	LSMEAN Number
1	-0.02650000	1
2	-0.01200000	2
3	0.01683333	3

Least Squares Means for effect Pass
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: LNCOR

i/j	1	2	3
1		0.9989	0.9901
2	0.9989		0.9956
3	0.9901	0.9956	

Analysis of CO concentrations over the course of a day W/ pit fan OFF- comparison of pass 1 177
09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: LNCOR LNCOR

Contrast	DF	Contrast SS	Mean Square	F Value	Pr > F
1 VS 2	1	0.00063075	0.00063075	0.00	0.9647
2 vs 3	1	0.00249408	0.00249408	0.01	0.9299
1 vs 3	1	0.00563333	0.00563333	0.02	0.8949
1&2 vs 3	1	0.00520803	0.00520803	0.02	0.8989
1 VS 2&3	1	0.00334469	0.00334469	0.01	0.9189
2 VS 1&3	1	0.00334469	0.00334469	0.01	0.9189

Hypothesis1: Concentration Change Over Time

Throughout the Course of a Sample Day

Nonparametric Statistics

Dust: Pit Fan On

Proc NPAR1WAY DATA=ONdustsasC WILCOXON;
Title ‘Nonparametric test to compare pass **1**, **2**, **3** dust concentrations’;
Class pass;
VAR dustr;

Run;

```
        'Nonparametric test to compare pass 1, 2, 3 dust concentrations'            178
                                                  09:19 Wednesday, March 7, 2012

                            The NPAR1WAY Procedure
                  Wilcoxon Scores (Rank Sums) for Variable DustR
                           Classified by Variable Pass

                                  Sum of      Expected       Std Dev          Mean
          Pass         N          Scores      Under H0      Under H0         Score

          1           21           913.0         672.0     68.582420     43.476190
          2           21           852.0         672.0     68.582420     40.571429
          3           21           251.0         672.0     68.582420     11.952381

                        Average scores were used for ties.

                               Kruskal-Wallis Test

                            Chi-Square         37.9461
                            DF                       2
                            Pr > Chi-Square     <.0001
```

Dust: Pit Fan Off

Proc NPAR1WAY DATA=OFFdustsasC WILCOXON;
Title 'Nonparametric test to compare pass **1**, **2**, **3** dust concentrations-OFF';
Class pass;
VAR dustr;
Run;

```
 'Nonparametric test to compare pass 1, 2, 3 dust concentrations-OFF'          179
                                              09:19 Wednesday, March 7, 2012
                            The NPAR1WAY Procedure
                  Wilcoxon Scores (Rank Sums) for Variable DustR
                           Classified by Variable Pass

                                  Sum of      Expected       Std Dev          Mean
          Pass         N          Scores      Under H0      Under H0         Score

          1           14           394.0         301.0     37.472809     28.142857
          2           14           366.0         301.0     37.472809     26.142857
          3           14           143.0         301.0     37.472809     10.214286

                        Average scores were used for ties.
                               Kruskal-Wallis Test

                            Chi-Square         17.9641
                            DF                       2
                            Pr > Chi-Square     0.0001
```

CO_2: Pit Fan On

Proc NPAR1WAY DATA=ONCO2sasC WILCOXON;
Title 'Nonparametric test to compare pass **1**, **2**, **3** CO2 concentrations-ON';
Class pass;
VAR CO2r;

Run;

```
'Nonparametric test to compare pass 1, 2, 3 CO2 concentrations-ON'            180
                                                09:19 Wednesday, March 7, 2012
                                   The NPAR1WAY Procedure
                        Wilcoxon Scores (Rank Sums) for Variable CO2R
                                 Classified by Variable Pass

                                 Sum of      Expected       Std Dev          Mean
             Pass        N       Scores      Under H0      Under H0         Score

             1          12       142.50         222.0     29.789739     11.875000
             2          12       269.00         222.0     29.789739     22.416667
             3          12       254.50         222.0     29.789739     21.208333

                              Average scores were used for ties.
                                      Kruskal-Wallis Test

                                   Chi-Square         7.2010
                                   DF                      2
                                   Pr > Chi-Square    0.0273
```

<u>CO_2: Pit Fan Off</u>

Proc NPAR1WAY DATA=OFFCO2sasC WILCOXON;
Title 'Nonparametric test to compare pass **1**, **2**, **3** CO2 concentrations-OFF';
Class pass;
VAR CO2r;
Run;

```
'Nonparametric test to compare pass 1, 2, 3 CO2 concentrations-OFF'          181
                                            09:19 Wednesday, March 7, 2012

                              The NPAR1WAY Procedure
                   Wilcoxon Scores (Rank Sums) for Variable CO2R
                            Classified by Variable Pass

                            Sum of      Expected       Std Dev          Mean
        Pass        N       Scores      Under H0      Under H0         Score

        1           8         37.0         100.0     16.329932        4.6250
        2           8        127.0         100.0     16.329932       15.8750
        3           8        136.0         100.0     16.329932       17.0000


                               Kruskal-Wallis Test

                            Chi-Square         14.9850
                            DF                       2
                            Pr > Chi-Square     0.0006
```

<u>NH_3: Pit Fan On</u>

Proc NPAR1WAY DATA=ONNH3sasC WILCOXON;
Title 'Nonparametric test to compare pass **1**, **2**, **3** NH3 concentrations-ON';
Class pass;
VAR NH3r;
Run;

```
'Nonparametric test to compare pass 1, 2, 3 NH3 concentrations-ON'            10
```

```
                                         15:00 Friday, March 9, 2012
                         The NPAR1WAY Procedure
               Wilcoxon Scores (Rank Sums) for Variable NH3R
                        Classified by Variable Pass
                        Sum of      Expected       Std Dev          Mean
    Pass        N       Scores      Under H0      Under H0         Score

    1           9        118.0         126.0     19.338085     13.111111
    2           9        121.0         126.0     19.338085     13.444444
    3           9        139.0         126.0     19.338085     15.444444

                     Average scores were used for ties.

                            Kruskal-Wallis Test

                          Chi-Square         0.4599
                          DF                      2
                          Pr > Chi-Square    0.7946
```

<u>NH_3: Pit Fan Off</u>

Proc NPAR1WAY DATA=OFFNH3sasC WILCOXON;
Title 'Nonparametric test to compare pass **1**, **2**, **3** NH3 concentrations-OFF';
Class pass;
VAR NH3r;
Run;

```
   'Nonparametric test to compare pass 1, 2, 3 NH3 concentrations-OFF'          183
                                        09:19 Wednesday, March 7, 2012
                      The NPAR1WAY Procedure
               Wilcoxon Scores (Rank Sums) for Variable NH3R
                       Classified by Variable Pass

                        Sum of      Expected       Std Dev          Mean
    Pass        N       Scores      Under H0      Under H0         Score

    1           6         49.0          57.0     10.677078      8.166667
    2           6         54.0          57.0     10.677078      9.000000
    3           6         68.0          57.0     10.677078     11.333333

                            Kruskal-Wallis Test

                          Chi-Square         1.1345
                          DF                      2
                          Pr > Chi-Square    0.5671
```

<u>H_2S: Pit Fan On</u>

Proc NPAR1WAY DATA=ONH2SsasC WILCOXON;
Title 'Nonparametric test to compare pass **1**, **2**, **3** H2S concentrations-ON';
Class pass;
VAR H2Sr;
Run;

```
        'Nonparametric test to compare pass 1, 2, 3 H2S concentrations-ON'          11
                                           15:00 Friday, March 9, 2012

                         The NPAR1WAY Procedure

               Wilcoxon Scores (Rank Sums) for Variable H2SR
```

```
                    Classified by Variable Pass

                    Sum of      Expected       Std Dev          Mean
Pass        N       Scores      Under H0      Under H0         Score

1           9        122.0         126.0     19.082815     13.555556
2           9        125.0         126.0     19.082815     13.888889
3           9        131.0         126.0     19.082815     14.555556

                 Average scores were used for ties.


                         Kruskal-Wallis Test

                      Chi-Square         0.0769
                      DF                      2
                      Pr > Chi-Square    0.9623
```

<u>H_2S: Pit Fan Off</u>

Proc NPAR1WAY DATA=OFFH2SsasC WILCOXON;
Title 'Nonparametric test to compare pass **1**, **2**, **3** H2S concentrations-OFF';
Class pass;
VAR H2Sr;
Run;

```
'Nonparametric test to compare pass 1, 2, 3 H2S concentrations-OFF'          185
                                           09:19 Wednesday, March 7, 2012
                             The NPAR1WAY Procedure
                  Wilcoxon Scores (Rank Sums) for Variable H2SR
                           Classified by Variable Pass

                    Sum of      Expected       Std Dev          Mean
Pass        N       Scores      Under H0      Under H0         Score

1           6         45.0          57.0     10.677078      7.500000
2           6         64.0          57.0     10.677078     10.666667
3           6         62.0          57.0     10.677078     10.333333

                         Kruskal-Wallis Test

                      Chi-Square         1.2749
                      DF                      2
                      Pr > Chi-Square    0.5287
```

<u>CO: Pit Fan On</u>

Proc NPAR1WAY DATA=ONCOsasC WILCOXON;
Title 'Nonparametric test to compare pass **1**, **2**, **3** CO concentrations-ON';
Class pass;
VAR COr;
Run;

```
'Nonparametric test to compare pass 1, 2, 3 CO concentrations-ON'           186
                                           09:19 Wednesday, March 7, 2012
                           The NPAR1WAY Procedure
                  Wilcoxon Scores (Rank Sums) for Variable COR
                           Classified by Variable Pass

                    Sum of      Expected       Std Dev          Mean
Pass        N       Scores      Under H0      Under H0         Score
```

1	9	150.50	126.0	19.439254	16.722222
2	9	123.00	126.0	19.439254	13.666667
3	9	104.50	126.0	19.439254	11.611111

```
                    Average scores were used for ties.

                          Kruskal-Wallis Test
                       Chi-Square        1.8903
                       DF                     2
                       Pr > Chi-Square    0.3886
```

CO: Pit Fan Off

Proc NPAR1WAY DATA=OFFCOsasC WILCOXON;
Title 'Nonparametric test to compare pass **1**, **2**, **3** CO concentrations-OFF';
Class pass;
VAR COr;
Run;

```
    'Nonparametric test to compare pass 1, 2, 3 CO concentrations-OFF'            187
                                                09:19 Wednesday, March 7, 2012

                          The NPAR1WAY Procedure
                 Wilcoxon Scores (Rank Sums) for Variable COR
                         Classified by Variable Pass
```

Pass	N	Sum of Scores	Expected Under H0	Std Dev Under H0	Mean Score
1	6	55.0	57.0	10.677078	9.166667
2	6	56.0	57.0	10.677078	9.333333
3	6	60.0	57.0	10.677078	10.000000

```
                          Kruskal-Wallis Test

                       Chi-Square        0.0819
                       DF                     2

                       Pr > Chi-Square    0.9599
```

Hypothesis 2: Comparison of Pit Fan Off vs On Concentrations

Parametric Statistics

Dust: No Transformation

PROC GLM Data=dustsasA;
Title 'ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM';
Class day pass setting;

Model dustr=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
run;

ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 11
09:19 Wednesday, March 7, 2012

The GLM Procedure
Class Level Information

Class	Levels	Values
Day	5	1 2 3 4 5
Pass	3	1 2 3
Setting	2	off on

Number of Observations Read	15
Number of Observations Used	15

ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 12
09:19 Wednesday, March 7, 2012
The GLM Procedure

Dependent Variable: DUSTR DUSTR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.06756840	0.06756840	6.83	0.0214
Error	13	0.12858133	0.00989087		
Corrected Total	14	0.19614973			

R-Square	Coeff Var	Root MSE	DUSTR Mean
0.344474	25.93520	0.099453	0.383467

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	0.06756840	0.06756840	6.83	0.0214

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	0.06756840	0.06756840	6.83	0.0214

Standard

Parameter		Estimate		Error	t Value	Pr > |t|
Intercept		0.3286666667	B	0.03315095	9.91	<.0001
Setting	off	0.1370000000	B	0.05241626	2.61	0.0214
Setting	on	0.0000000000	B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 13
09:19 Wednesday, March 7, 2012
The GLM Procedure
Tukey's Studentized Range (HSD) Test for DUSTR
NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.009891
Critical Value of Studentized Range	3.05522

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
off - on	0.13700	0.02376	0.25024	***
on - off	-0.13700	-0.25024	-0.02376	***

ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 14
09:19 Wednesday, March 7, 2012
The GLM Procedure
Tukey's Studentized Range (HSD) Test for DUSTR
NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher
Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.009891
Critical Value of Studentized Range	3.05522
Minimum Significant Difference	0.1132
Harmonic Mean of Cell Sizes	7.2

NOTE: Cell sizes are not equal.
Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	Setting
A	0.46567	6	off
B	0.32867	9	on

ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 15
09:19 Wednesday, March 7, 2012
The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Setting	DUSTR LSMEAN	H0:LSMean1=LSMean2 Pr > |t|
off	0.46566667	0.0214
on	0.32866667	

<u>Dust: Log –transformed</u>

PROC GLM Data=dustsasA;
Title 'ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM';
Class day pass setting;
Model LNdustr=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
run;

```
ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM              16
                                          09:19 Wednesday, March 7, 2012

                                              The GLM Procedure

                                          Class Level Information

                                     Class         Levels    Values

                                     Day                5    1 2 3 4 5

                                     Pass               3    1 2 3

                                     Setting            2    off on


                                   Number of Observations Read          15
                                   Number of Observations Used          15
```

```
ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM              17
                                                       09:19 Wednesday, March 7, 2012
                                              The GLM Procedure
       Dependent Variable: LNDUSTR   LNDUSTR
                                                    Sum of
Source                        DF         Squares     Mean Square    F Value    Pr > F

Model                          1      0.43111601      0.43111601       6.75    0.0221

Error                         13      0.83073639      0.06390280

Corrected Total               14      1.26185240

          R-Square     Coeff Var      Root MSE    LNDUSTR Mean
```

0.341653	-25.25880	0.252790	-1.000800

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	0.43111601	0.43111601	6.75	0.0221

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	0.43111601	0.43111601	6.75	0.0221

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		-1.139222222 B	0.08426334	-13.52	<.0001
Setting	off	0.346055556 B	0.13323204	2.60	0.0221
Setting	on	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

The GLM Procedure
Tukey's Studentized Range (HSD) Test for LNDUSTR
NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.063903
Critical Value of Studentized Range	3.05522

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
off - on	0.3461	0.0582	0.6339	***
on - off	-0.3461	-0.6339	-0.0582	***

The GLM Procedure
Tukey's Studentized Range (HSD) Test for LNDUSTR
NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher
Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.063903
Critical Value of Studentized Range	3.05522
Minimum Significant Difference	0.2878
Harmonic Mean of Cell Sizes	7.2

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	Setting
A	-0.7932	6	off
B	-1.1392	9	on

```
                 The GLM Procedure
                Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

                                      H0:LSMean1=
                         LNDUSTR       LSMean2
     Setting              LSMEAN        Pr > |t|

     off             -0.79316667         0.0221
     on              -1.13922222
```

Dust: No Transformation

PROC GLM Data=dustsasb;
Title 'ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS';
Class day pass setting STATION;
Model dustr=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
run;

Below analyzes means for on vs off using individual 90 min station averages (n=105)
Mean dust concentration fan on =? Mean dust concentration fan off → adjusted tukey

Setting	DustR LSMEAN	Pr > |t|
off	0.46564286	<.0001
on	0.32868254	

mean "off" concentration is significantly different than mean "on" concentration (p<0.0001)

```
ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS         21
                                                        09:19 Wednesday, March 7, 2012

                                   The GLM Procedure
                                Class Level Information
                            Class         Levels    Values

                            Day                5    1 2 3 4 5

                            Pass               3    1 2 3

                            Setting            2    off on

                            Station            7    A B C D E F G

                            Number of Observations Read         105
                            Number of Observations Used         105

ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS         22
                                                       09:19 Wednesday, March 7, 2012
                                   The GLM Procedure
Dependent Variable: DustR   DustR
                                          Sum of
Source                      DF          Squares     Mean Square    F Value    Pr > F
```

Model	1	0.47270484	0.47270484	46.13	<.0001
Error	103	1.05543129	0.01024691		
Corrected Total	104	1.52813613			

R-Square	Coeff Var	Root MSE	DustR Mean
0.309334	26.39786	0.101227	0.383467

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	0.47270484	0.47270484	46.13	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	0.47270484	0.47270484	46.13	<.0001

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		0.3286825397 B	0.01275340	25.77	<.0001
Setting	off	0.1369603175 B	0.02016490	6.79	<.0001
Setting	on	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

The GLM Procedure
Tukey's Studentized Range (HSD) Test for DustR
NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	103
Error Mean Square	0.010247
Critical Value of Studentized Range	2.80476

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
off - on	0.13696	0.09697	0.17695	***
on - off	-0.13696	-0.17695	-0.09697	***

The GLM Procedure
Tukey's Studentized Range (HSD) Test for DustR
NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher
Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	103
Error Mean Square	0.010247
Critical Value of Studentized Range	2.80476
Minimum Significant Difference	0.04
Harmonic Mean of Cell Sizes	50.4

```
                NOTE: Cell sizes are not equal.
  Means with the same letter are not significantly different.

Tukey Grouping          Mean      N    Setting

             A       0.46564     42     off

             B       0.32868     63     on
```

```
ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS         25
                                                09:19 Wednesday, March 7, 2012

                          The GLM Procedure
                          Least Squares Means
               Adjustment for Multiple Comparisons: Tukey-Kramer

                                              H0:LSMean1=
                                                LSMean2
                     Setting    DustR LSMEAN      Pr > |t|

                     off          0.46564286        <.0001
                     on           0.32868254
```

<u>Dust: Log-transformed</u>

```
PROC GLM Data=dustsasb;
Title 'ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS';
Class day pass setting STATION;
Model LNdustr=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
run;
```

Below analyzes means for on vs off using LN TRANSFORMED individual 90 min station averages (n=105)
Mean LNdust concentration fan on =? Mean LNdust concentration fan off → adjusted tukey

```
                                        H0:LSMean1=
                             LnDustR      LSMean2
           Setting            LSMEAN      Pr > |t|

            off          -0.79690476        <.0001
            on           -1.14376190
```

mean "off" concentration is significantly different than mean "on" concentration (p<0.0001)

```
ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS         26
                                                          09:19 Wednesday, March
7, 2012

                          The GLM Procedure

                        Class Level Information
```

Class	Levels	Values
Day	5	1 2 3 4 5
Pass	3	1 2 3
Setting	2	off on
Station	7	A B C D E F G

Number of Observations Read 105
Number of Observations Used 105

The GLM Procedure

Dependent Variable: LnDustR LnDustR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	3.03180891	3.03180891	46.92	<.0001
Error	103	6.65621105	0.06462341		
Corrected Total	104	9.68801996			

R-Square	Coeff Var	Root MSE	LnDustR Mean
0.312944	-25.29418	0.254211	-1.005019

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	3.03180891	3.03180891	46.92	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	3.03180891	3.03180891	46.92	<.0001

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		-1.143761905 B	0.03202762	-35.71	<.0001
Setting	off	0.346857143 B	0.05064011	6.85	<.0001
Setting	on	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

The GLM Procedure

Tukey's Studentized Range (HSD) Test for LnDustR

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	103
Error Mean Square	0.064623
Critical Value of Studentized Range	2.80476

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
off - on	0.34686	0.24642	0.44729	***
on - off	-0.34686	-0.44729	-0.24642	***

```
     ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS         29
                                                    09:19 Wednesday, March 7, 2012
                                        The GLM Procedure
                        Tukey's Studentized Range (HSD) Test for LnDustR
 NOTE: This test controls the Type I experimentwise error rate, but it generally has a
higher
                                 Type II error rate than REGWQ.

                         Alpha                                      0.05
                         Error Degrees of Freedom                    103
                         Error Mean Square                      0.064623
                         Critical Value of Studentized Range  2.80476
                         Minimum Significant Difference         0.1004
                         Harmonic Mean of Cell Sizes              50.4

                                 NOTE: Cell sizes are not equal.

                  Means with the same letter are not significantly different.

                  Tukey Grouping          Mean      N    Setting

                               A      -0.79690     42    off

                               B      -1.14376     63    on
```

```
     ANALYSIS OF DUST CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS         30
                                                      09:19 Wednesday, March 7, 2012

                                        The GLM Procedure
                                       Least Squares Means
                        Adjustment for Multiple Comparisons: Tukey-Kramer

                                                      H0:LSMean1=
                                        LnDustR         LSMean2
                          Setting        LSMEAN          Pr > |t|

                          off         -0.79690476          <.0001
                          on          -1.14376190
```

CO_2: No Transformation

PROC GLM Data=CO2sasA;
Title 'ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM';
Class day pass set
Model CO2r=setti
means setting/tuk
means setting/tuk
lsmeans setting/Pl
rUN;

ANALYSIS OF CO_2 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 31
09:19 Wednesday, March 7, 2012

The GLM Procedure
Class Level Information

Class	Levels	Values
Day	5	1 2 3 4 5
Pass	3	1 2 3
Setting	2	off on

Number of Observations Read	15
Number of Observations Used	15

ANALYSIS OF CO_2 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 32
09:19 Wednesday, March 7, 2012
The GLM Procedure
Dependent Variable: CO2R CO2R

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1922478.498	1922478.498	24.03	0.0003
Error	13	1040255.776	80019.675		
Corrected Total	14	2962734.273			

R-Square	Coeff Var	Root MSE	CO2R Mean
0.648887	8.778454	282.8775	3222.407

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	1922478.498	1922478.498	24.03	0.0003

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	1922478.498	1922478.498	24.03	0.0003

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		2930.099511 B	94.2924971	31.07	<.0001
Setting	off	730.767956 B	149.0895285	4.90	0.0003
Setting	on	0.000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

ANALYSIS OF CO_2 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 33
09:19 Wednesday, March 7, 2012
The GLM Procedure
Tukey's Studentized Range (HSD) Test for CO2R
NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	80019.68
Critical Value of Studentized Range	3.05522

Comparisons significant at the 0.05 level are indicated by ***

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits

off - on	730.8	408.7	1052.9	***
on - off	-730.8	-1052.9	-408.7	***

The GLM Procedure
Tukey's Studentized Range (HSD) Test for CO2R
NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher
Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	80019.68
Critical Value of Studentized Range	3.05522
Minimum Significant Difference	322.09
Harmonic Mean of Cell Sizes	7.2

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	Setting
A	3660.9	6	off
B	2930.1	9	on

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Setting	CO2R LSMEAN	H0:LSMean1= LSMean2 Pr > |t|
off	3660.86747	0.0003
on	2930.09951	

CO_2: Log-transformed

PROC GLM Data=CO2sasA;
Title 'ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM';
Class day pass setting;
Model LNCO2r=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
rUN;

```
ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM              36
                                          09:19 Wednesday, March 7, 2012
                              The GLM Procedure

                            Class Level Information
                         Class         Levels    Values

                         Day                5    1 2 3 4 5

                         Pass               3    1 2 3

                         Setting            2    off on

                       Number of Observations Read          15
                       Number of Observations Used          15
```

```
ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM              37
                                             09:19 Wednesday, March 7, 2012
                              The GLM Procedure

Dependent Variable: LNCO2R   LNCO2R

                                             Sum of
      Source                      DF        Squares     Mean Square    F Value    Pr > F

      Model                        1     0.17181093      0.17181093      25.44    0.0002

      Error                       13     0.08781204      0.00675477

      Corrected Total             14     0.25962297


                      R-Square     Coeff Var      Root MSE    LNCO2R Mean

                      0.661771      1.018561      0.082187       8.068973
```

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	0.17181093	0.17181093	25.44	0.0002

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	0.17181093	0.17181093	25.44	0.0002

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		7.981588889 B	0.02739581	291.34	<.0001
Setting	off	0.218461111 B	0.04331658	5.04	0.0002
Setting	on	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 38
09:19 Wednesday, March 7, 2012

The GLM Procedure
Tukey's Studentized Range (HSD) Test for LNCO2R

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.006755
Critical Value of Studentized Range	3.05522

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
off - on	0.21846	0.12488	0.31204	***
on - off	-0.21846	-0.31204	-0.12488	***

ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 39
09:19 Wednesday, March 7, 2012

The GLM Procedure
Tukey's Studentized Range (HSD) Test for LNCO2R
NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher
Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.006755
Critical Value of Studentized Range	3.05522
Minimum Significant Difference	0.0936
Harmonic Mean of Cell Sizes	7.2

NOTE: Cell sizes are not equal.
Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	Setting
A	8.20005	6	off
B	7.98159	9	on

ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 40
09:19 Wednesday, March 7, 2012

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Setting	LNCO2R LSMEAN	H0:LSMean1= LSMean2 Pr > |t|
off	8.20005000	0.0002
on	7.98158889	

CO_2: No Transformation

```
PROC GLM Data=CO2sasb;
Title 'ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS';
Class day pass setting STATION;
Model CO2r=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
run;
```

ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 41
09:19 Wednesday, March 7, 2012

The GLM Procedure

Class Level Information

Class	Levels	Values
Day	5	1 2 3 4 5
Pass	3	1 2 3
Setting	2	off on
Station	4	A C E G

Number of Observations Read	60
Number of Observations Used	60

ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 42
09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: CO2R CO2R

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	7666169.88	7666169.88	90.30	<.0001
Error	58	4923764.97	84892.50		
Corrected Total	59	12589934.85			

R-Square	Coeff Var	Root MSE	CO2R Mean
0.608913	9.039983	291.3632	3223.050

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	7666169.878	7666169.878	90.30	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	7666169.878	7666169.878	90.30	<.0001

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		2931.194444 B	48.56052910	60.36	<.0001
Setting	off	729.638889 B	76.78093817	9.50	<.0001
Setting	on	0.000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 43
09:19 Wednesday, March 7, 2012

The GLM Procedure

Tukey's Studentized Range (HSD) Test for CO2R

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	58
Error Mean Square	84892.5
Critical Value of Studentized Range	2.83086

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
off - on	729.64	575.95	883.33	***
on - off	-729.64	-883.33	-575.95	***

The GLM Procedure

Tukey's Studentized Range (HSD) Test for CO2R

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	58
Error Mean Square	84892.5
Critical Value of Studentized Range	2.83086
Minimum Significant Difference	153.69
Harmonic Mean of Cell Sizes	28.8

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	Setting
A	3660.83	24	off
B	2931.19	36	on

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Setting	CO2R LSMEAN	H0:LSMean1= LSMean2 Pr > |t|
off	3660.83333	<.0001
on	2931.19444	

CO_2: Log-transformed

```
PROC GLM Data=CO2sasb;
Title 'ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-
INDIVIDUAL STATIONS';
Class day pass setting STATION;
Model LNCO2r=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
run;
```

```
ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS          46
                                                       09:19 Wednesday, March 7, 2012

                                  The GLM Procedure

                               Class Level Information

                          Class          Levels    Values

                          Day                 5    1 2 3 4 5

                          Pass                3    1 2 3

                          Setting             2    off on

                          Station             4    A C E G


                        Number of Observations Read          60
                        Number of Observations Used          60
```

ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 47
09:19 Wednesday, March 7, 2012
The GLM Procedure
Dependent Variable: LnCO2R LnCO2R

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.68138401	0.68138401	95.45	<.0001
Error	58	0.41403364	0.00713851		
Corrected Total	59	1.09541765			

R-Square	Coeff Var	Root MSE	LnCO2R Mean
0.622031	1.047136	0.084490	8.068650

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	0.68138401	0.68138401	95.45	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	0.68138401	0.68138401	95.45	<.0001

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		7.981638889 B	0.01408162	566.81	<.0001
Setting	off	0.217527778 B	0.02226499	9.77	<.0001
Setting	on	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 48
09:19 Wednesday, March 7, 2012
The GLM Procedure
Tukey's Studentized Range (HSD) Test for LnCO2R
NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	58
Error Mean Square	0.007139
Critical Value of Studentized Range	2.83086

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
off - on	0.21753	0.17296	0.26210	***
on - off	-0.21753	-0.26210	-0.17296	***

ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 49
09:19 Wednesday, March 7, 2012
The GLM Procedure
Tukey's Studentized Range (HSD) Test for LnCO2R
NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher
Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	58
Error Mean Square	0.007139
Critical Value of Studentized Range	2.83086
Minimum Significant Difference	0.0446
Harmonic Mean of Cell Sizes	28.8

```
                         NOTE: Cell sizes are not equal.

          Means with the same letter are not significantly different.
          Tukey Grouping          Mean      N    Setting

                       A       8.19917     24    off

                       B       7.98164     36    on
```

```
ANALYSIS OF CO2 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS          50
                                                  09:19 Wednesday, March 7, 2012
                                  The GLM Procedure
                                 Least Squares Means
                       Adjustment for Multiple Comparisons: Tukey-Kramer

                                                      H0:LSMean1=
                                           LnCO2R      LSMean2
                            Setting        LSMEAN       Pr > |t|

                            off          8.19916667       <.0001
                            on           7.98163889
```

NH$_3$: No Transformation

PROC GLM Data=NH3sasA;
Title 'ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM';
Class day pass setting;
Model NH3r=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
rUN;

```
ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM              51
                                                     09:19 Wednesday, March 7, 2012
                                   The GLM Procedure
                               Class Level Information

                              Class         Levels    Values

                              Day                5    1 2 3 4 5
```

Pass	3	1 2 3
Setting	2	off on

Number of Observations Read 15
Number of Observations Used 15

ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 5

09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: NH3R NH3R

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	71.0222500	71.0222500	4.25	0.0600
Error	13	217.4840833	16.7295449		
Corrected Total	14	288.5063333			

R-Square	Coeff Var	Root MSE	NH3R Mean
0.246172	71.79947	4.090177	5.696667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	71.02225000	71.02225000	4.25	0.0600

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	71.02225000	71.02225000	4.25	0.0600

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		3.920000000 B	1.36339221	2.88	0.0130
Setting	off	4.441666667 B	2.15571236	2.06	0.0600
Setting	on	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 53
09:19 Wednesday, March 7, 2012
The GLM Procedure

Tukey's Studentized Range (HSD) Test for NH3R
NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	16.72954
Critical Value of Studentized Range	3.05522

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits	
off - on	4.442	-0.215	9.099
on - off	-4.442	-9.099	0.215

```
ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM              54
                                                     09:19 Wednesday, March 7, 2012
                                       The GLM Procedure
                         Tukey's Studentized Range (HSD) Test for NH3R
 NOTE: This test controls the Type I experimentwise error rate, but it generally has a
higher
                                Type II error rate than REGWQ.
                         Alpha                                        0.05
                         Error Degrees of Freedom                       13
                         Error Mean Square                        16.72954
                         Critical Value of Studentized Range  3.05522
                         Minimum Significant Difference        4.6571
                         Harmonic Mean of Cell Sizes              7.2

                                NOTE: Cell sizes are not equal.
                  Means with the same letter are not significantly different.
                  Tukey Grouping          Mean      N    Setting

                               A         8.362      6    off
                               A
                               A         3.920      9    on
```

```
ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM              55
                                                                 09:19 Wednesday, March
7, 2012
                                      The GLM Procedure
                                      Least Squares Means
                       Adjustment for Multiple Comparisons: Tukey-Kramer
                                                       H0:LSMean1=
                                                         LSMean2
                            Setting     NH3R LSMEAN       Pr > |t|

                            off          8.36166667         0.0600
                            on           3.92000000
```

<u>NH_3: Log-transformed</u>

PROC GLM Data=NH3sasA;
Title 'ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM';
Class day pass setting;
Model LNNH3r=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
rUN;

The GLM Procedure

Class Level Information

Class	Levels	Values
Day	5	1 2 3 4 5
Pass	3	1 2 3
Setting	2	off on

Number of Observations Read	15
Number of Observations Used	15

The GLM Procedure

Dependent Variable: LNNH3R LNNH3R

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	36.0240400	36.0240400	4.29	0.0588
Error	13	109.1209133	8.3939164		
Corrected Total	14	145.1449533			

R-Square	Coeff Var	Root MSE	LNNH3R Mean
0.248194	1308.987	2.897226	0.221333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	36.02404000	36.02404000	4.29	0.0588

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	36.02404000	36.02404000	4.29	0.0588

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		-1.044000000 B	0.96574188	-1.08	0.2993
Setting	off	3.163333333 B	1.52697199	2.07	0.0588
Setting	on	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

The GLM Procedure

Tukey's Studentized Range (HSD) Test for LNNH3R

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	8.393916
Critical Value of Studentized Range	3.05522

```
             Comparisons significant at the 0.05 level are indicated by ***.

                                  Difference      Simultaneous
                     Setting         Between     95% Confidence
                    Comparison         Means         Limits

                    off - on           3.163     -0.135   6.462
                    on  - off         -3.163     -6.462   0.135
```

```
ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM              20
                                                        15:00 Friday, March 9, 2012
                                 The GLM Procedure
                    Tukey's Studentized Range (HSD) Test for LNNH3R
 NOTE: This test controls the Type I experimentwise error rate, but it generally has a
higher
                             Type II error rate than REGWQ.


                         Alpha                                    0.05
                         Error Degrees of Freedom                   13
                         Error Mean Square                    8.393916
                         Critical Value of Studentized Range  3.05522
                         Minimum Significant Difference        3.2988
                         Harmonic Mean of Cell Sizes              7.2

                                NOTE: Cell sizes are not equal.


                  Means with the same letter are not significantly different.


                  Tukey Grouping          Mean      N    Setting

                               A         2.119      6    off
                               A
                               A        -1.044      9    on
```

```
ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM              21
                                                  15:00 Friday, March 9, 2012
                                 The GLM Procedure
                                Least Squares Means
                    Adjustment for Multiple Comparisons: Tukey-Kramer

                                                     H0:LSMean1=
                                        LNNH3R         LSMean2
                          Setting       LSMEAN        Pr > |t|

                          off         2.11933333        0.0588
                          on         -1.04400000
```

NH_3: No Transformation

PROC GLM Data=NH3sasb;
Title 'ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS';
Class day pass setting STATION;
Model NH3r=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;

run;

ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 61
09:19 Wednesday, March 7, 2012
The GLM Procedure
Class Level Information

Class	Levels	Values
Day	5	1 2 3 4 5
Pass	3	1 2 3
Setting	2	off on
Station	3	B C F

Number of Observations Read	45
Number of Observations Used	45

ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 62
09:19 Wednesday, March 7, 2012
The GLM Procedure
Dependent Variable: NH3R NH3R

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	213.066750	213.066750	11.61	0.0014
Error	43	789.182050	18.353071		
Corrected Total	44	1002.248800			

R-Square	Coeff Var	Root MSE	NH3R Mean
0.212589	75.20272	4.284048	5.696667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	213.0667500	213.0667500	11.61	0.0014

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	213.0667500	213.0667500	11.61	0.0014

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		3.920000000 B	0.82446550	4.75	<.0001
Setting	off	4.441666667 B	1.30359442	3.41	0.0014
Setting	on	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to

```
     solve the normal equations.  Terms whose estimates are followed by the letter 'B'
are not uniquely estimable.
```

```
ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS          63
                                               09:19 Wednesday, March 7, 2012
                                The GLM Procedure
                    Tukey's Studentized Range (HSD) Test for NH3R
                NOTE: This test controls the Type I experimentwise error rate.

                         Alpha                                     0.05
                         Error Degrees of Freedom                    43
                         Error Mean Square                     18.35307
                         Critical Value of Studentized Range  2.85203

                Comparisons significant at the 0.05 level are indicated by ***.

                                Difference      Simultaneous
                     Setting       Between     95% Confidence
                    Comparison       Means          Limits

                    off - on         4.442      1.813   7.071  ***
                    on  - off       -4.442     -7.071  -1.813  ***
```

```
ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS          64
                                               09:19 Wednesday, March 7, 2012
                                The GLM Procedure
                    Tukey's Studentized Range (HSD) Test for NH3R
 NOTE: This test controls the Type I experimentwise error rate, but it generally has a
higher
                           Type II error rate than REGWQ.

                         Alpha                                     0.05
                         Error Degrees of Freedom                    43
                         Error Mean Square                     18.35307
                         Critical Value of Studentized Range  2.85203
                         Minimum Significant Difference         2.6289
                         Harmonic Mean of Cell Sizes              21.6

                           NOTE: Cell sizes are not equal.

                  Means with the same letter are not significantly different.

                  Tukey Grouping          Mean      N    Setting

                               A         8.362     18    off

                               B         3.920     27    on
```

```
ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS          65
                                           09:19 Wednesday, March 7, 2012

                                The GLM Procedure
                               Least Squares Means
                      Adjustment for Multiple Comparisons: Tukey-Kramer

                                                  H0:LSMean1=
                                                    LSMean2
                          Setting     NH3R LSMEAN      Pr > |t|

                          off          8.36166667        0.0014
                          on           3.9200000
```

NH_3: Log-transformed

PROC GLM Data=NH3sasb;

Title 'ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS';
Class day pass setting STATION;
Model LNNH3r=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
run;

ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 22
15:00 Friday, March 9, 2012

The GLM Procedure

Class Level Information

Class	Levels	Values
Day	5	1 2 3 4 5
Pass	3	1 2 3
Setting	2	off on
Station	3	B C F

Number of Observations Read	45
Number of Observations Used	45

ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 23
15:00 Friday, March 9, 2012
The GLM Procedure
Dependent Variable: LNNH3R LNNH3R

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	121.1306508	121.1306508	14.28	0.0005
Error	43	364.7818118	8.4832979		
Corrected Total	44	485.9124626			

R-Square	Coeff Var	Root MSE	LNNH3R Mean
0.249285	9914.331	2.912610	0.029378

Source	DF	Type I SS	Mean Square	F Value	Pr > F

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	121.1306508	121.1306508	14.28	0.0005
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	121.1306508	121.1306508	14.28	0.0005

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		-1.310222222 B	0.56053209	-2.34	0.0241
Setting	off	3.349000000 B	0.88627905	3.78	0.0005
Setting	on	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 24
15:00 Friday, March 9, 2012

The GLM Procedure

Tukey's Studentized Range (HSD) Test for LNNH3R

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	43
Error Mean Square	8.483298
Critical Value of Studentized Range	2.85203

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
off - on	3.3490	1.5616	5.1364	***
on - off	-3.3490	-5.1364	-1.5616	***

ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 25
15:00 Friday, March 9, 2012
The GLM Procedure
Tukey's Studentized Range (HSD) Test for LNNH3R

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher
Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	43
Error Mean Square	8.483298
Critical Value of Studentized Range	2.85203
Minimum Significant Difference	1.7874
Harmonic Mean of Cell Sizes	21.6

NOTE: Cell sizes are not equal.
Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	Setting
A	2.0388	18	off
B	-1.3102	27	on

ANALYSIS OF NH3 CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 26

```
                                     15:00 Friday, March 9, 2012

                      The GLM Procedure
                     Least Squares Means
        Adjustment for Multiple Comparisons: Tukey-Kramer

                                          H0:LSMean1=
                           LNNH3R           LSMean2
             Setting       LSMEAN          Pr > |t|

             off         2.03877778          0.0005
             on         -1.31022222
```

H_2S: No Transformation

PROC GLM Data=H2SsasA;
Title 'ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM';
Class day pass setting;
Model H2Sr=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
rUN;

```
ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM              71
                                         09:19 Wednesday, March 7, 2012
                     The GLM Procedure
                   Class Level Information
              Class        Levels    Values

              Day               5    1 2 3 4 5

              Pass              3    1 2 3

              Setting           2    off on

            Number of Observations Read          15
            Number of Observations Used          15
```

ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 72
09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: H2SR H2SR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.49343218	0.49343218	15.64	0.0016
Error	13	0.41023356	0.03155643		
Corrected Total	14	0.90366573			

R-Square	Coeff Var	Root MSE	H2SR Mean
0.546034	69.15700	0.177641	0.256867

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	0.49343218	0.49343218	15.64	0.0016

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	0.49343218	0.49343218	15.64	0.0016

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		0.1087777778 B	0.05921376	1.84	0.0892
Setting	off	0.3702222222 B	0.09362518	3.95	0.0016
Setting	on	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 73
09:19 Wednesday, March 7, 2012

The GLM Procedure

Tukey's Studentized Range (HSD) Test for H2SR

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.031556
Critical Value of Studentized Range	3.05522

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
off - on	0.37022	0.16796	0.57249	***
on - off	-0.37022	-0.57249	-0.16796	***

ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 74
09:19 Wednesday, March 7, 2012

The GLM Procedure

Tukey's Studentized Range (HSD) Test for H2SR

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.031556
Critical Value of Studentized Range	3.05522
Minimum Significant Difference	0.2023
Harmonic Mean of Cell Sizes	7.2

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	Setting
A	0.47900	6	off
B	0.10878	9	on

ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 75
09:19 Wednesday, March 7, 2012

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Setting	H2SR LSMEAN	H0:LSMean1= LSMean2 Pr > |t|
off	0.47900000	0.0016
on	0.10877778	

<u>H_2S: Log-transformed</u>

PROC GLM Data=H2SsasA;
Title 'ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM';
Class day pass setting;
Model LNH2Sr=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
rUN;

ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 27
15:00 Friday, March 9, 2012
The GLM Procedure

Class Level Information

Class	Levels	Values
Day	5	1 2 3 4 5

Pass	3	1 2 3
Setting	2	off on

Number of Observations Read	15
Number of Observations Used	15

ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 28
15:00 Friday, March 9, 2012
The GLM Procedure
Dependent Variable: LNH2SR LNH2SR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	32.96161284	32.96161284	9.12	0.0099
Error	13	46.98415089	3.61416545		
Corrected Total	14	79.94576373			

R-Square	Coeff Var	Root MSE	LNH2SR Mean
0.412300	-71.82439	1.901096	-2.646867

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	32.96161284	32.96161284	9.12	0.0099

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	32.96161284	32.96161284	9.12	0.0099

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		-3.857222222 B	0.63369862	-6.09	<.0001
Setting	off	3.025888889 B	1.00196549	3.02	0.0099
Setting	on	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 29
15:00 Friday, March 9, 2012

The GLM Procedure
Tukey's Studentized Range (HSD) Test for LNH2SR

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	3.614165
Critical Value of Studentized Range	3.05522

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
off - on	3.0259	0.8613	5.1905	***
on - off	-3.0259	-5.1905	-0.8613	***

ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 30
15:00 Friday, March 9, 2012
The GLM Procedure

```
                    Tukey's Studentized Range (HSD) Test for LNH2SR
 NOTE: This test controls the Type I experimentwise error rate, but it generally has a
higher
                            Type II error rate than REGWQ.
                         Alpha                                  0.05
                         Error Degrees of Freedom                 13
                         Error Mean Square                  3.614165
                         Critical Value of Studentized Range  3.05522
                         Minimum Significant Difference       2.1646
                         Harmonic Mean of Cell Sizes             7.2
                            NOTE: Cell sizes are not equal.
                  Means with the same letter are not significantly different.

                  Tukey Grouping          Mean      N    Setting

                               A        -0.831      6    off

                               B        -3.857      9    on
```

```
ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM              31
                                                                    15:00 Friday, March
9, 2012

                                   The GLM Procedure
                                  Least Squares Means
                       Adjustment for Multiple Comparisons: Tukey-Kramer

                                                      H0:LSMean1=
                                            LNH2SR      LSMean2
                           Setting          LSMEAN       Pr > |t|

                           off         -0.83133333         0.0099
                           on          -3.85722222
```

H_2S: No Transformation

PROC GLM Data=H2Ssasb;
Title 'ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS';
Class day pass setting STATION;
Model H2Sr=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
run;

```
ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS          81
```

09:19 Wednesday, March 7, 2012

The GLM Procedure

Class Level Information

Class	Levels	Values
Day	5	1 2 3 4 5
Pass	3	1 2 3
Setting	2	off on
Station	3	B C F

Number of Observations Read	45
Number of Observations Used	45

ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 82

09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: H2SR H2SR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1.48177779	1.48177779	46.38	<.0001
Error	43	1.37384741	0.03194994		
Corrected Total	44	2.85562520			

R-Square	Coeff Var	Root MSE	H2SR Mean
0.518898	69.58687	0.178745	0.256867

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	1.48177779	1.48177779	46.38	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	1.48177779	1.48177779	46.38	<.0001

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		0.1087037037 B	0.03439958	3.16	0.0029
Setting	off	0.3704074074 B	0.05439051	6.81	<.0001
Setting	on	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 83

09:19 Wednesday, March 7, 2012

The GLM Procedure

Tukey's Studentized Range (HSD) Test for H2SR

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	43
Error Mean Square	0.03195
Critical Value of Studentized Range	2.85203

Comparisons significant at the 0.05 level are indicated by ***.

```
                     Difference
 Setting               Between     Simultaneous 95%
Comparison               Means    Confidence Limits

off - on               0.37041     0.26072  0.48010  ***
on  - off             -0.37041    -0.48010 -0.26072  ***
```

```
ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS          84
                                                      09:19 Wednesday, March 7, 2012

                                 The GLM Procedure
                  Tukey's Studentized Range (HSD) Test for H2SR
 NOTE: This test controls the Type I experimentwise error rate, but it generally has a
higher
                         Type II error rate than REGWQ.

                  Alpha                                   0.05
                  Error Degrees of Freedom                  43
                  Error Mean Square                    0.03195
                  Critical Value of Studentized Range  2.85203
                  Minimum Significant Difference        0.1097
                  Harmonic Mean of Cell Sizes             21.6

                         NOTE: Cell sizes are not equal.

             Means with the same letter are not significantly different.

             Tukey Grouping          Mean      N    Setting

                          A       0.47911     18    off

                          B       0.10870     27    on
```

```
ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS          85
                                                    09:19 Wednesday, March 7, 2012
                                 The GLM Procedure
                                Least Squares Means
                  Adjustment for Multiple Comparisons: Tukey-Kramer
                                                   H0:LSMean1=
                                                     LSMean2
                   Setting     H2SR LSMEAN       Pr > |t|

                   off          0.47911111         <.0001
                   on           0.10870370
```

H_2S: Log-transformed

PROC GLM Data=H2Ssasb;
Title 'ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS';
Class day pass setting STATION;
Model LNH2Sr=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;

run;

ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 32
15:00 Friday, March 9, 2012

The GLM Procedure

Class Level Information

Class	Levels	Values
Day	5	1 2 3 4 5
Pass	3	1 2 3
Setting	2	off on
Station	3	B C F

Number of Observations Read	45
Number of Observations Used	45

ANALYSIS OF H2S CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 33
15:00 Friday, March 9, 2012

The GLM Procedure

Dependent Variable: LNH2SR LNH2SR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	122.1831737	122.1831737	31.19	<.0001
Error	43	168.4383601	3.9171712		
Corrected Total	44	290.6215338			

R-Square	Coeff Var	Root MSE	LNH2SR Mean
0.420420	-69.24530	1.979184	-2.858222

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	122.1831737	122.1831737	31.19	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	122.1831737	122.1831737	31.19	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|

Intercept		-4.203629630 B	0.38089423	-11.04	<.0001
Setting	off	3.363518519 B	0.60224666	5.58	<.0001
Setting	on	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

The GLM Procedure
Tukey's Studentized Range (HSD) Test for LNH2SR

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	43
Error Mean Square	3.917171
Critical Value of Studentized Range	2.85203

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		
off - on	3.3635	2.1490	4.5781	***
on - off	-3.3635	-4.5781	-2.1490	***

The GLM Procedure
Tukey's Studentized Range (HSD) Test for LNH2SR

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	43
Error Mean Square	3.917171
Critical Value of Studentized Range	2.85203
Minimum Significant Difference	1.2145
Harmonic Mean of Cell Sizes	21.6

NOTE: Cell sizes are not equal.
Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	Setting
A	-0.8401	18	off
B	-4.2036	27	on

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey-Kramer

Setting	LNH2SR LSMEAN	H0:LSMean1= LSMean2 Pr > |t|
off	-0.84011111	<.0001
on	-4.20362963	

<u>CO: No Transformation</u>

PROC GLM Data=COsasA;
Title 'ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM';
Class day pass setting;
Model COr=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
rUN;

```
ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM               91
                                         09:19 Wednesday, March 7, 2012
                                       The GLM Procedure
                                   Class Level Information

                              Class         Levels    Values

                              Day                5    1 2 3 4 5

                              Pass               3    1 2 3

                              Setting            2    off on

                            Number of Observations Read         15
                            Number of Observations Used         15
```

```
ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM               92
                                         09:19 Wednesday, March 7, 2012
                                       The GLM Procedure
Dependent Variable: COR   COR
                                                 Sum of
      Source                      DF           Squares     Mean Square    F Value    Pr > F

      Model                        1        0.00693444      0.00693444       0.09    0.7677

      Error                       13        0.99057956      0.07619843

      Corrected Total             14        0.99751400

                      R-Square     Coeff Var      Root MSE      COR Mean

                      0.006952      24.17168      0.276041      1.142000
```

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	0.00693444	0.00693444	0.09	0.7677

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	0.00693444	0.00693444	0.09	0.7677

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		1.159555556 B	0.09201354	12.60	<.0001
Setting	off	-0.043888889 B	0.14548618	-0.30	0.7677
Setting	on	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 93
09:19 Wednesday, March 7, 2012

The GLM Procedure

Tukey's Studentized Range (HSD) Test for COR

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.076198
Critical Value of Studentized Range	3.05522

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits	
on - off	0.04389	-0.27041	0.35819
off - on	-0.04389	-0.35819	0.27041

ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 94
09:19 Wednesday, March 7, 2012

The GLM Procedure

Tukey's Studentized Range (HSD) Test for COR

NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.076198
Critical Value of Studentized Range	3.05522
Minimum Significant Difference	0.3143
Harmonic Mean of Cell Sizes	7.2

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping	Mean	N	Setting
A	1.1596	9	on
A			
A	1.1157	6	off

ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 95
09:19 Wednesday, March 7, 2012

The GLM Procedure

Least Squares Means

```
                    Adjustment for Multiple Comparisons: Tukey-Kramer

                                                 H0:LSMean1=
                                                   LSMean2
                         Setting      COR LSMEAN     Pr > |t|

                         off          1.11566667       0.7677
                         on           1.15955556
```

<u>CO: Log-transformed</u>

```
PROC GLM Data=COsasA;
Title 'ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM';
Class day pass setting;
Model LNCOr=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
rUN;
```

```
ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM               96
                                                    09:19 Wednesday, March 7, 2012
                                      The GLM Procedure
                                   Class Level Information

                              Class         Levels    Values

                              Day                5    1 2 3 4 5

                              Pass               3    1 2 3

                              Setting            2    off on

                            Number of Observations Read         15
                            Number of Observations Used         15
```

ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 97
09:19 Wednesday, March 7, 2012
The GLM Procedure
Dependent Variable: LNCOR LNCOR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00018204	0.00018204	0.00	0.9566
Error	13	0.76757089	0.05904391		
Corrected Total	14	0.76775293			

R-Square	Coeff Var	Root MSE	LNCOR Mean
0.000237	226.5285	0.242990	0.107267

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	0.00018204	0.00018204	0.00	0.9566

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	0.00018204	0.00018204	0.00	0.9566

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		0.1101111111 B	0.08099651	1.36	0.1971
Setting	off	-.0071111111 B	0.12806673	-0.06	0.9566
Setting	on	0.0000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 98
09:19 Wednesday, March 7, 2012
The GLM Procedure
Tukey's Studentized Range (HSD) Test for LNCOR
NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.059044
Critical Value of Studentized Range	3.05522

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits	
on - off	0.007111	-0.269560	0.283782
off - on	-0.007111	-0.283782	0.269560

ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM 99
09:19 Wednesday, March 7, 2012
The GLM Procedure
Tukey's Studentized Range (HSD) Test for LNCOR
NOTE: This test controls the Type I experimentwise error rate, but it generally has a higher
Type II error rate than REGWQ.

Alpha	0.05
Error Degrees of Freedom	13
Error Mean Square	0.059044

```
Critical Value of Studentized Range  3.05522
Minimum Significant Difference        0.2767
Harmonic Mean of Cell Sizes              7.2

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

Tukey Grouping          Mean      N    Setting

             A        0.1101      9    on
             A
             A        0.1030      6    off
```

```
ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-TOTAL ROOM              100
                                              09:19 Wednesday, March 7, 2012

                              The GLM Procedure
                             Least Squares Means
                Adjustment for Multiple Comparisons: Tukey-Kramer

                                                H0:LSMean1=
                                                  LSMean2
                   Setting    LNCOR LSMEAN         Pr > |t|

                   off          0.10300000          0.9566
                   on           0.11011111
```

<u>CO: No Transformation</u>

PROC GLM Data=COsasb;
Title 'ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS';
Class day pass setting STATION;
Model COr=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
run;

```
ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS        101
                                             09:19 Wednesday, March 7, 2012
                              The GLM Procedure
                           Class Level Information

                      Class         Levels    Values
```

Day	5	1 2 3 4 5
Pass	3	1 2 3
Setting	2	off on
Station	3	B C F

Number of Observations Read 45
Number of Observations Used 45

The GLM Procedure

Dependent Variable: COR COR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.02080333	0.02080333	0.08	0.7827
Error	43	11.61379111	0.27008817		
Corrected Total	44	11.63459444			

R-Square	Coeff Var	Root MSE	COR Mean
0.001788	45.51232	0.519700	1.141889

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	0.02080333	0.02080333	0.08	0.7827

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	0.02080333	0.02080333	0.08	0.7827

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		1.159444444 B	0.10001633	11.59	<.0001
Setting	off	-0.043888889 B	0.15813970	-0.28	0.7827
Setting	on	0.000000000 B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.

The GLM Procedure

Tukey's Studentized Range (HSD) Test for COR

NOTE: This test controls the Type I experimentwise error rate.

Alpha	0.05
Error Degrees of Freedom	43
Error Mean Square	0.270088
Critical Value of Studentized Range	2.85203

Comparisons significant at the 0.05 level are indicated by ***.

Setting Comparison	Difference Between Means	Simultaneous 95% Confidence Limits

```
                  on  - off        0.04389    -0.27503  0.36281
                  off - on        -0.04389    -0.36281  0.27503
```

```
ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS         104
                                                       09:19 Wednesday, March 7, 2012
                                    The GLM Procedure
                      Tukey's Studentized Range (HSD) Test for COR
 NOTE: This test controls the Type I experimentwise error rate, but it generally has a
higher
                             Type II error rate than REGWQ.

                      Alpha                                      0.05
                      Error Degrees of Freedom                     43
                      Error Mean Square                      0.270088
                      Critical Value of Studentized Range  2.85203
                      Minimum Significant Difference        0.3189
                      Harmonic Mean of Cell Sizes              21.6

                             NOTE: Cell sizes are not equal.

                  Means with the same letter are not significantly different.

                  Tukey Grouping          Mean      N    Setting

                               A        1.1594     27    on
                               A
                               A        1.1156     18    off
```

```
ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS         105
                                                     09:19 Wednesday, March 7, 2012
                                    The GLM Procedure
                                   Least Squares Means
                     Adjustment for Multiple Comparisons: Tukey-Kramer

                                                     H0:LSMean1=
                                                       LSMean2
                         Setting      COR LSMEAN        Pr > |t|

                         off          1.11555556          0.7827
                         on           1.15944444
```

<u>CO: Log-transformed</u>

PROC GLM Data=COsasb;
Title 'ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS';
Class day pass setting STATION;
Model LNCOr=setting/solution;
means setting/tukey cldiff;
means setting/tukey lines;
lsmeans setting/PDIFF adjust=tukey;
run;

ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 106

The GLM Procedure

Class Level Information

Class	Levels	Values
Day	5	1 2 3 4 5
Pass	3	1 2 3
Setting	2	off on
Station	3	B C F

Number of Observations Read	45
Number of Observations Used	45

ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS 107

09:19 Wednesday, March 7, 2012

The GLM Procedure

Dependent Variable: LNCOR LNCOR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	0.00091117	0.00091117	0.00	0.9627
Error	43	17.70893163	0.41183562		
Corrected Total	44	17.70984280			

R-Square	Coeff Var	Root MSE	LNCOR Mean
0.000051	-5039.876	0.641744	-0.012733

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Setting	1	0.00091117	0.00091117	0.00	0.9627

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Setting	1	0.00091117	0.00091117	0.00	0.9627

Parameter		Estimate	Standard Error	t Value	Pr > |t|
Intercept		-.0164074074 B	0.12350373	-0.13	0.8949
Setting	off	0.0091851852 B	0.19527654	0.05	0.9627
Setting	on	0.0000000000 B	.	.	.

```
NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to
      solve the normal equations.  Terms whose estimates are followed by the letter 'B'
are not uniquely estimable.
```

```
ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS         108
                                                         09:19 Wednesday, March 7, 2012
                                       The GLM Procedure
                          Tukey's Studentized Range (HSD) Test for LNCOR
                  NOTE: This test controls the Type I experimentwise error rate.

                         Alpha                                      0.05
                         Error Degrees of Freedom                     43
                         Error Mean Square                      0.411836
                         Critical Value of Studentized Range     2.85203

                  Comparisons significant at the 0.05 level are indicated by ***.

                                   Difference
                       Setting        Between      Simultaneous 95%
                      Comparison        Means     Confidence Limits

                      off - on       0.009185    -0.384627  0.402998
                      on  - off     -0.009185    -0.402998  0.384627
```

```
ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS         109
                                                       09:19 Wednesday, March 7, 2012
                                       The GLM Procedure
                          Tukey's Studentized Range (HSD) Test for LNCOR
 NOTE: This test controls the Type I experimentwise error rate, but it generally has a
higher
                                 Type II error rate than REGWQ.

                         Alpha                                      0.05
                         Error Degrees of Freedom                     43
                         Error Mean Square                      0.411836
                         Critical Value of Studentized Range     2.85203
                         Minimum Significant Difference           0.3938
                         Harmonic Mean of Cell Sizes                21.6
                                NOTE: Cell sizes are not equal.

                    Means with the same letter are not significantly different.

                    Tukey Grouping          Mean      N    Setting

                                 A      -0.00722     18    off
                                 A
                                 A      -0.01641     27    on
```

```
ANALYSIS OF CO CONCENTRATIONS FOR PIT FAN OFF VS ON-INDIVIDUAL STATIONS         110
                                                      09:19 Wednesday, March 7, 2012

                                       The GLM Procedure
                                      Least Squares Means
                         Adjustment for Multiple Comparisons: Tukey-Kramer

                                                        H0:LSMean1=
                                                          LSMean2
                            Setting    LNCOR LSMEAN       Pr > |t|

                            off         -0.00722222         0.9627
                            on          -0.01640741
```

Hypothesis 2: Comparison of Pit Fan Off vs On Concentrations

Nonparametric Statistics

Dust

Proc NPAR1WAY DATA=dustsasb WILCOXON;
Title ‘Nonparametric test to compare pit fan on dust concentrations vs off’;
Class setting;
VAR dustr;
Run;

```
     ‘Nonparametric test to compare pit fan on dust concentrations vs off’         116
                                                   09:19 Wednesday, March 7, 2012
                                  The NPAR1WAY Procedure
                        Wilcoxon Scores (Rank Sums) for Variable DustR
                                Classified by Variable Setting

                                  Sum of      Expected       Std Dev           Mean
            Setting       N       Scores      Under H0      Under H0          Score

            on           63       2490.0        3339.0    152.876364      39.523810
            off          42       3075.0        2226.0    152.876364      73.214286
                            Average scores were used for ties.
                                  Wilcoxon Two-Sample Test
                                Statistic             3075.0000

                                Normal Approximation
                                Z                        5.5502
                                One-Sided Pr >  Z        <.0001
                                Two-Sided Pr > |Z|       <.0001

                                t Approximation
                                One-Sided Pr >  Z        <.0001
                                Two-Sided Pr > |Z|       <.0001
                           Z includes a continuity correction of 0.5.
                                      Kruskal-Wallis Test

                                Chi-Square              30.8414
                                DF                            1
                                Pr > Chi-Square          <.0001
```

$\underline{CO_2}$

Proc NPAR1WAY DATA=co2sasb WILCOXON;
Title ‘Nonparametric test to compare CO2 concentrations: Pit fan on vs off’;
Class setting;
VAR co2r;
Run;

```
‘Nonparametric test to compare CO2 concentrations: Pit fan on vs off’          117
                                                09:19 Wednesday, March 7, 2012

                              The NPAR1WAY Procedure

                   Wilcoxon Scores (Rank Sums) for Variable CO2R
                          Classified by Variable Setting

                              Sum of      Expected       Std Dev          Mean
     Setting         N        Scores      Under H0      Under H0         Score

     on             36         699.0        1098.0     66.267562     19.416667
     off            24        1131.0         732.0     66.267562     47.125000

                         Average scores were used for ties.


                             Wilcoxon Two-Sample Test

                          Statistic             1131.0000

                          Normal Approximation
                          Z                        6.0135
                          One-Sided Pr >  Z        <.0001
                          Two-Sided Pr > |Z|       <.0001

                          t Approximation
                          One-Sided Pr >  Z        <.0001
                          Two-Sided Pr > |Z|       <.0001

                      Z includes a continuity correction of 0.5.


                                Kruskal-Wallis Test

                          Chi-Square              36.2530
                          DF                            1
                          Pr > Chi-Square          <.0001
```

$\underline{NH_3}$

```
Proc NPAR1WAY DATA=nh3sasb WILCOXON;
Title 'Nonparametric test to compare nh3 concentrations: Pit fan on vs off';
Class setting;
VAR nh3r;
Run;
```

```
  'Nonparametric test to compare nh3 concentrations: Pit fan on vs off'         118
                                                   09:19 Wednesday, March 7, 2012

                                The NPAR1WAY Procedure

                      Wilcoxon Scores (Rank Sums) for Variable NH3R
                             Classified by Variable Setting

                                 Sum of      Expected       Std Dev          Mean
          Setting        N       Scores      Under H0      Under H0         Score

          on            27        506.0         621.0     43.082796     18.740741
          off           18        529.0         414.0     43.082796     29.388889

                            Average scores were used for ties.


                                 Wilcoxon Two-Sample Test

                             Statistic             529.0000

                             Normal Approximation
                             Z                       2.6577
                             One-Sided Pr >  Z       0.0039
                             Two-Sided Pr > |Z|      0.0079

                             t Approximation
                             One-Sided Pr >  Z       0.0055
                             Two-Sided Pr > |Z|      0.0109

                        Z includes a continuity correction of 0.5.


                                  Kruskal-Wallis Test

                             Chi-Square              7.1251
                             DF                           1
                             Pr > Chi-Square         0.0076
```

H$_2$S

Proc NPAR1WAY DATA=h2ssasb WILCOXON;
Title 'Nonparametric test to compare h2s concentrations: Pit fan on vs off';
Class setting;
VAR h2sr;
Run;

```
'Nonparametric test to compare h2s concentrations: Pit fan on vs off'         119
                                       09:19 Wednesday, March 7, 2012

                              The NPAR1WAY Procedure

                    Wilcoxon Scores (Rank Sums) for Variable H2SR
                           Classified by Variable Setting

                             Sum of      Expected       Std Dev          Mean
        Setting       N      Scores      Under H0      Under H0         Score

        on           27      420.50         621.0     42.990115     15.574074
        off          18      614.50         414.0     42.990115     34.138889

                         Average scores were used for ties.


                             Wilcoxon Two-Sample Test

                           Statistic             614.5000

                           Normal Approximation
                           Z                       4.6522
                           One-Sided Pr >  Z       <.0001
                           Two-Sided Pr > |Z|      <.0001

                           t Approximation
                           One-Sided Pr >  Z       <.0001
                           Two-Sided Pr > |Z|      <.0001

                    Z includes a continuity correction of 0.5.


                              Kruskal-Wallis Test

                           Chi-Square             21.7516
                           DF                           1
                           Pr > Chi-Square         <.0001
```

<u>CO</u>

Proc NPAR1WAY DATA=cosasb WILCOXON;
Title ‘Nonparametric test to compare CO concentrations: Pit fan on vs off’;
Class setting;
VAR COr;
Run;

```
   ‘Nonparametric test to compare CO concentrations: Pit fan on vs off’          120
                                                  09:19 Wednesday, March 7, 2012

                                The NPAR1WAY Procedure

                     Wilcoxon Scores (Rank Sums) for Variable COR
                            Classified by Variable Setting

                               Sum of      Expected       Std Dev          Mean
          Setting       N      Scores      Under H0      Under H0         Score

          on           27       622.0         621.0     43.161062     23.037037
          off          18       413.0         414.0     43.161062     22.944444

                         Average scores were used for ties.


                              Wilcoxon Two-Sample Test

                            Statistic            413.0000

                            Normal Approximation
                            Z                     -0.0116
                            One-Sided Pr <  Z      0.4954
                            Two-Sided Pr > |Z|     0.9908

                            t Approximation
                            One-Sided Pr <  Z      0.4954
                            Two-Sided Pr > |Z|     0.9908

                     Z includes a continuity correction of 0.5.


                                Kruskal-Wallis Test

                            Chi-Square             0.0005
                            DF                          1
                            Pr > Chi-Square        0.9815
```

APPENDIX D: CONTAMINANT MAPS COMMUNICATING CONTAMINANT MAPPING AND FIXED-AREA STATION CONCENTRATION DISTRIBUTIONS

Mapping software (Surfer Version 10, Golden Software, Golden CO) was used to create distribution maps of respirable dust, CO_2, NH_3, H_2S, and CO concentrations for each sample day. Maps were created for both contaminant mapping and the concentrations collected by the instruments in the fixed area stations. The maps for the contaminant mapping were constructed by calculating an average concentration using the two-minute samples measured in the three events for each position. To construct one map for the fixed stationary instruments for each day, an average concentration was calculated using the three 90-minute event concentrations. A Kriging method was first used to create a grid for each contaminant for both mapping and fixed area measurements. The gridded data were used to develop two-dimensional maps of the contaminant distribution in the farrowing barn. A layout of the farrowing barn was positioned over the concentration maps to indicate areas of high concentrations. The mapping positions and the fixed area station locations are represented by black plus signs. The concentration maps were ordered by the manure pit fan setting. Days one, three, and five will be on one page and days two and four will be positioned on a separate page.

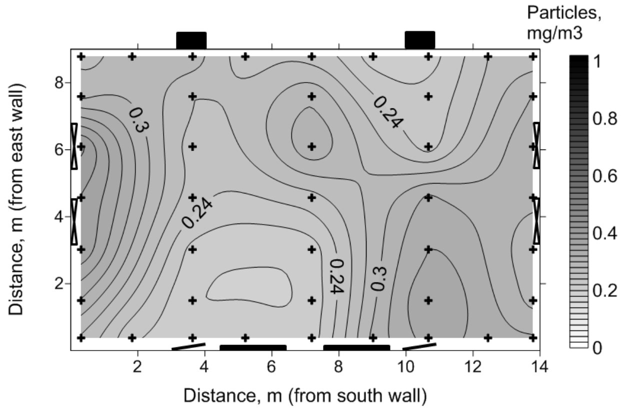

Figure D-1. Day 1 contaminant mapping of dust concentrations (pit fan on)

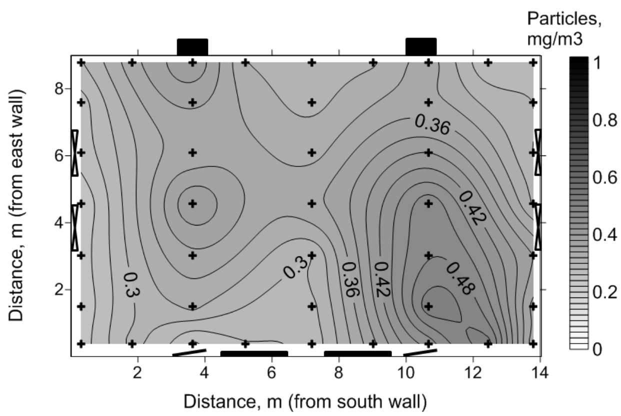

Figure D-2. Day 3 contaminant mapping of dust concentrations (pit fan on)

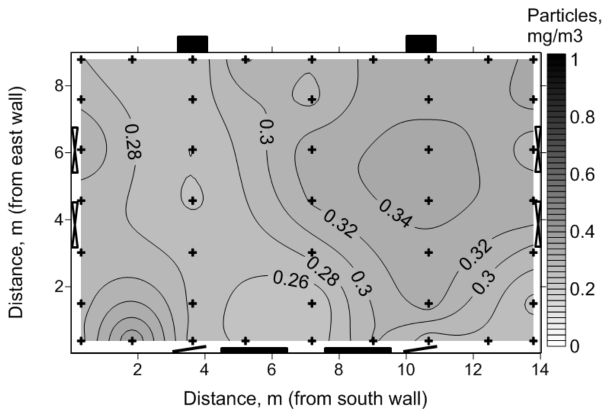

Figure D-3. Day 5 contaminant mapping of dust concentrations (pit fan on)

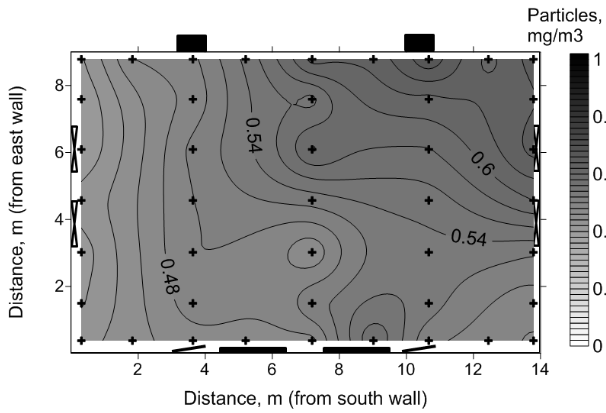

Figure D-4. Day 2 contaminant mapping of dust concentrations (pit fan off)

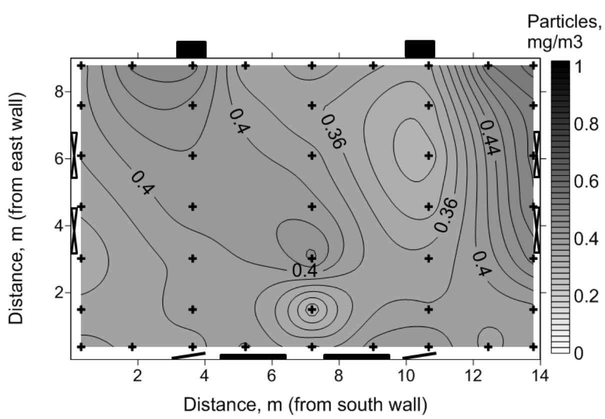

Figure D-5. Day 4 contaminant mapping of dust concentrations (pit fan off)

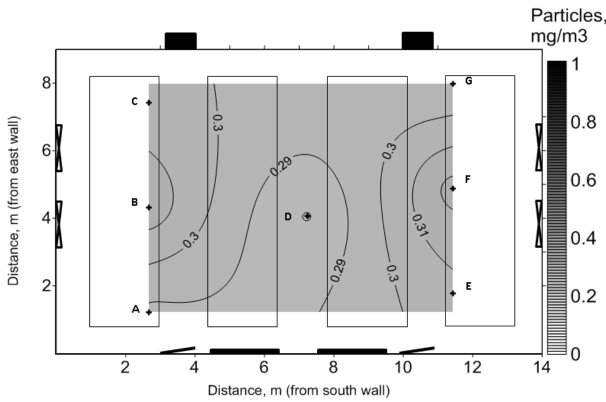

Figure D-6. Day 1 fixed area station mapping of dust concentrations (pit fan on)

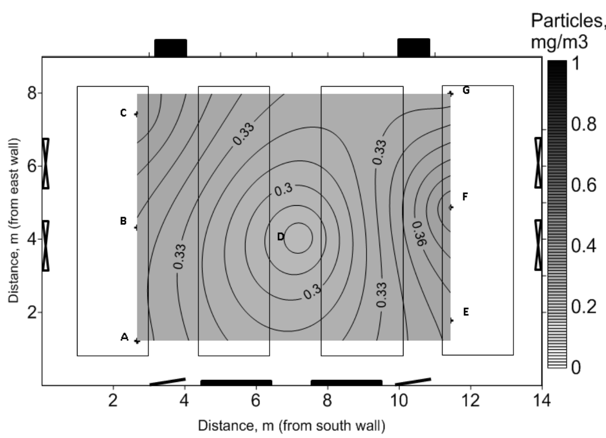

Figure D-7. Day 3 fixed area station mapping of dust concentrations (pit fan on)

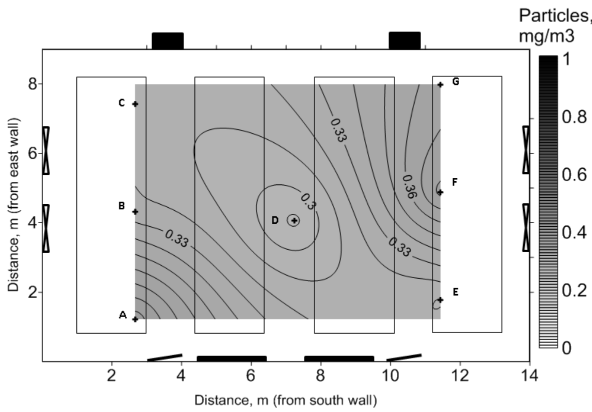

Figure D-8. Day 5 fixed area station mapping of dust concentrations (pit fan on)

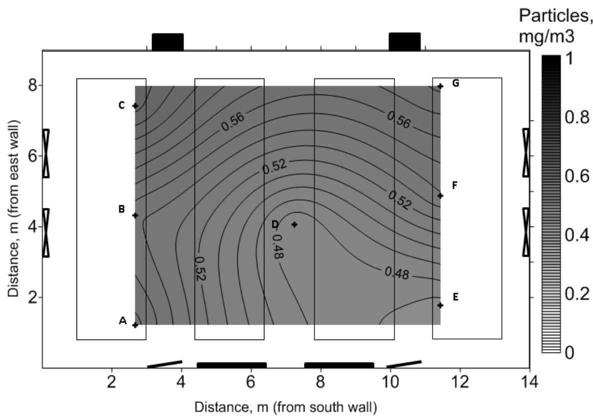

Figure D-9. Day 2 fixed area station mapping of dust concentrations (pit fan off)

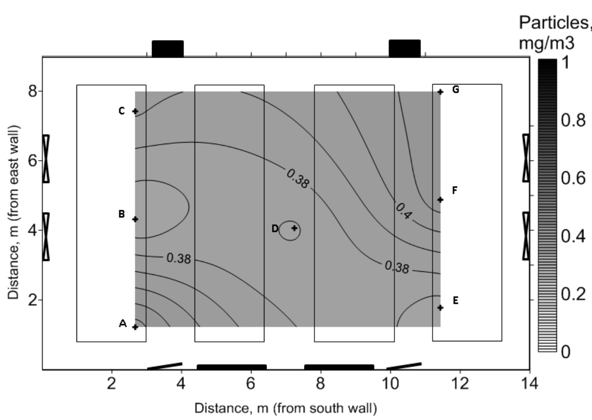

Figure D-10. Day 4 fixed area station mapping of dust concentrations (pit fan off)

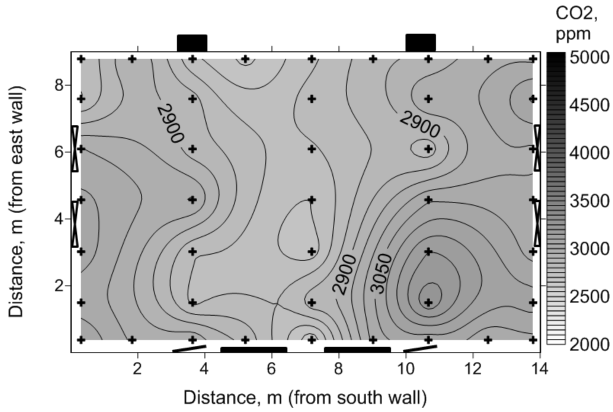

Figure D-11. Day 1 contaminant mapping of CO_2 concentrations (pit fan on)

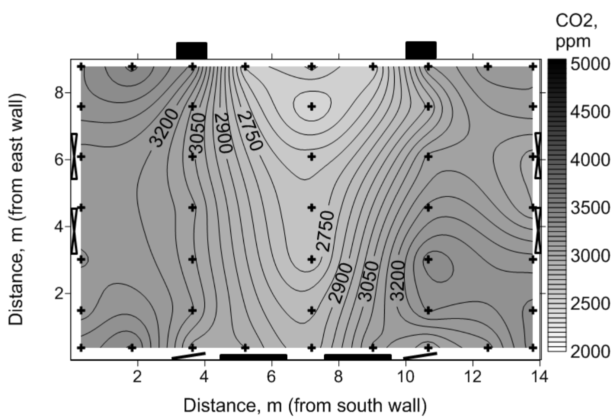

Figure D-12. Day 3 contaminant mapping of CO_2 concentrations (pit fan on)

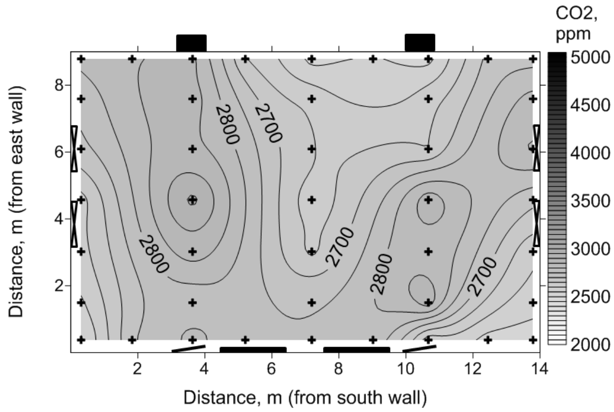

Figure D-13. Day 5 contaminant mapping of CO_2 concentrations (pit fan on)

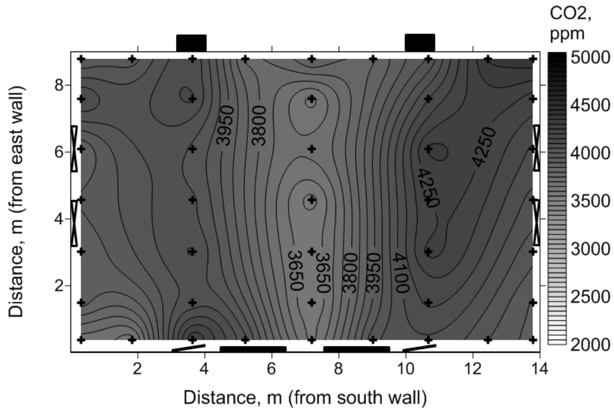

Figure D-14. Day 2 contaminant mapping of CO_2 concentrations (pit fan off)

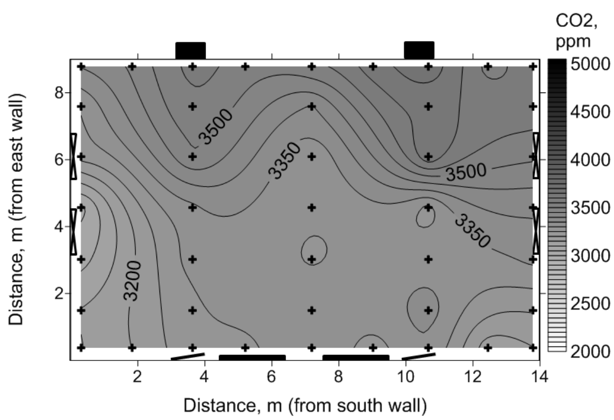

Figure D-15. Day 4 contaminant mapping of CO_2 concentrations (pit fan off)

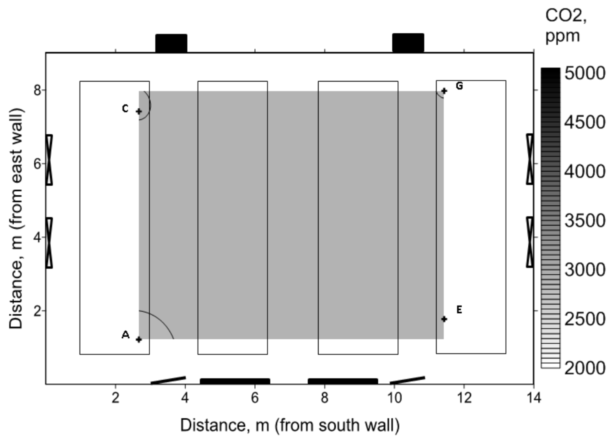

Figure D-16. Day 1 fixed area station mapping of CO_2 concentrations (pit fan on)

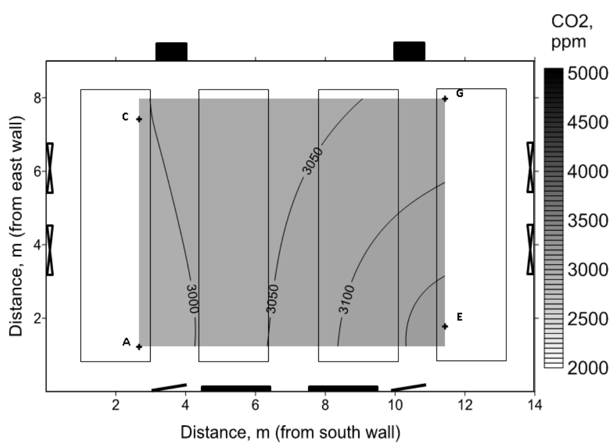

Figure D-17. Day 3 fixed area station mapping of CO_2 concentrations (pit fan on)

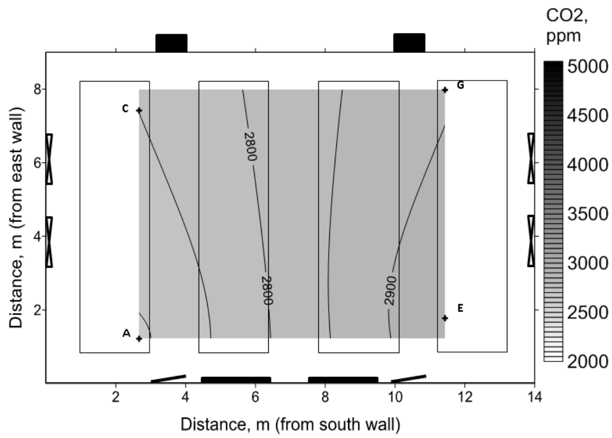

Figure D-18. Day 5 fixed area station mapping of CO_2 concentrations (pit fan on)

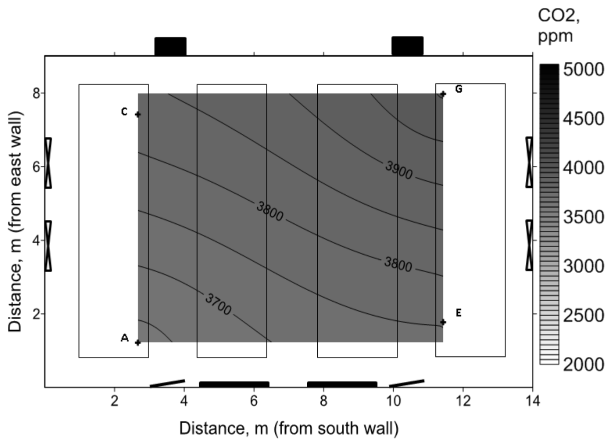

Figure D-19. Day 2 fixed area station mapping of CO_2 concentrations (pit fan off)

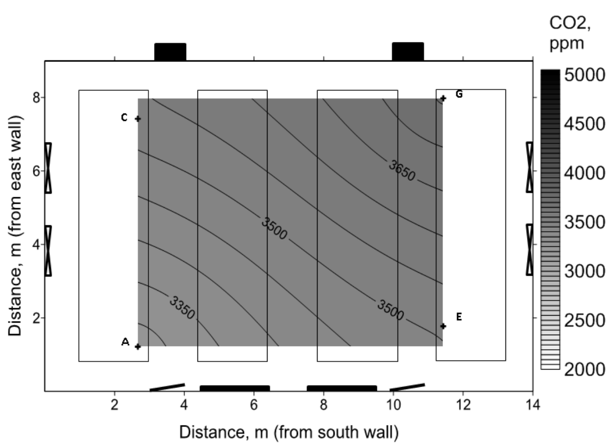

Figure D-20. Day 4 fixed area station mapping of CO_2 concentrations (pit fan off)

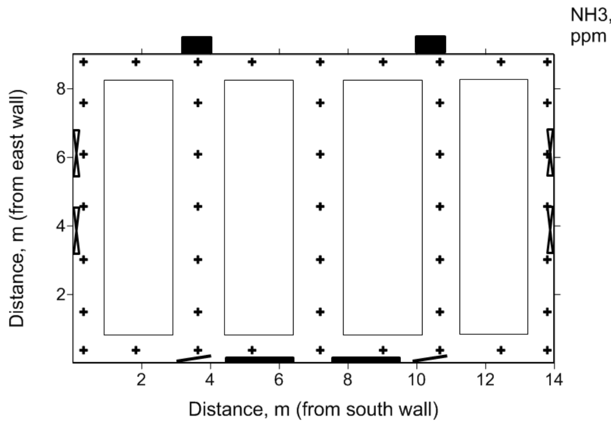

Figure D-21. Day 1 contaminant mapping of NH_3 concentrations (pit fan on)

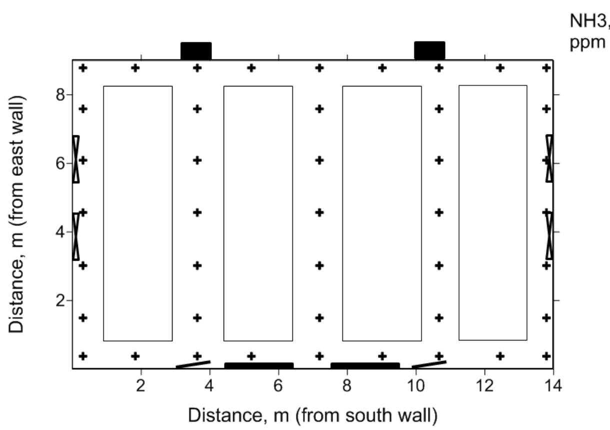

Figure D-22. Day 3 contaminant mapping of NH_3 concentrations (pit fan on)

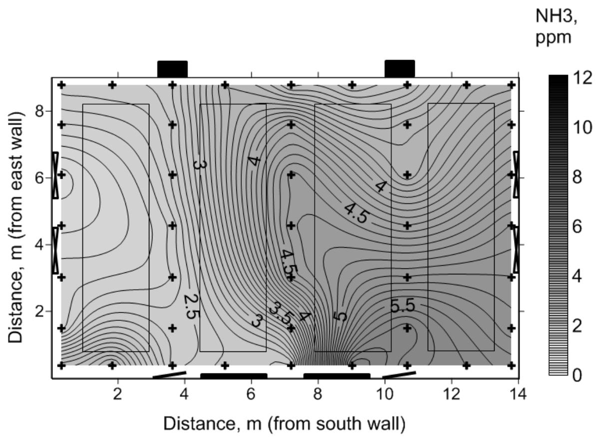

Figure D-23. Day 5 contaminant mapping of NH_3 concentrations (pit fan on)

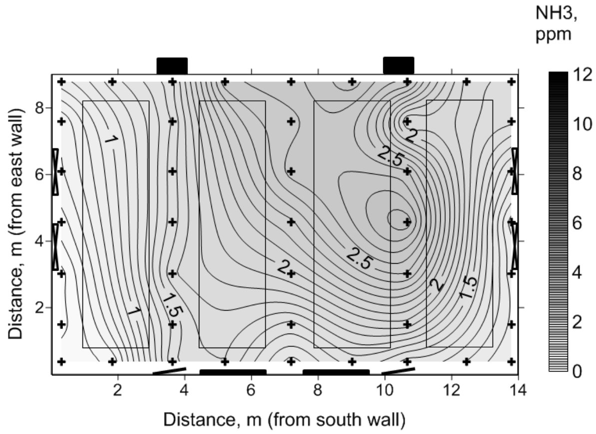

Figure D-24. Day 2 contaminant mapping of NH_3 concentrations (pit fan off)

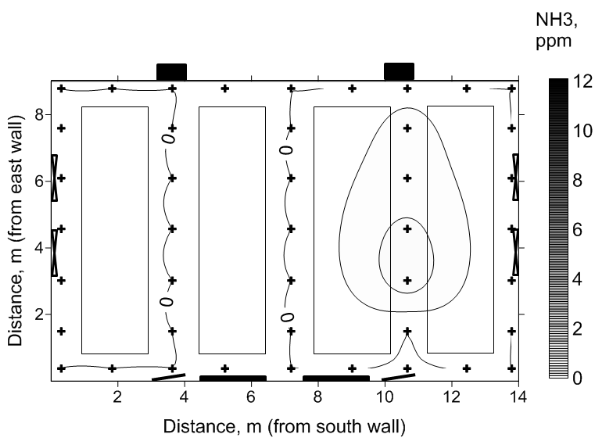

Figure D-25. Day 4 contaminant mapping of NH_3 concentrations (pit fan off)

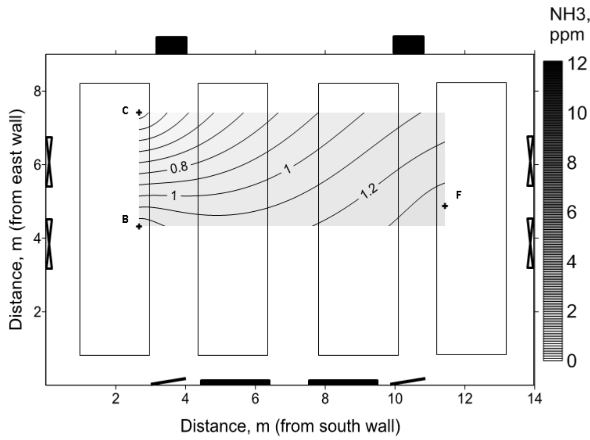

Figure D-26. Day 1 fixed area station mapping of NH_3 concentrations (pit fan on)

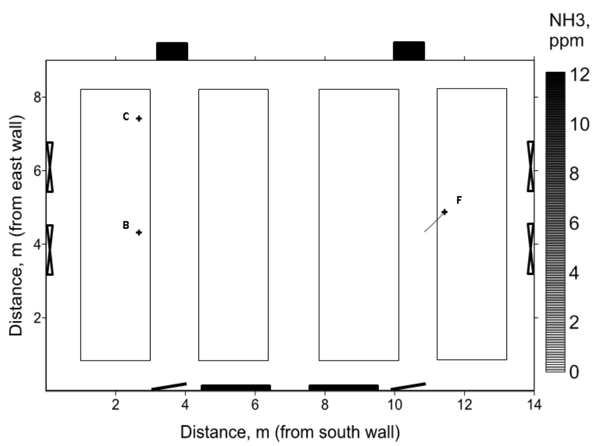

Figure D-27. Day 3 fixed area station mapping of NH_3 concentrations (pit fan on)

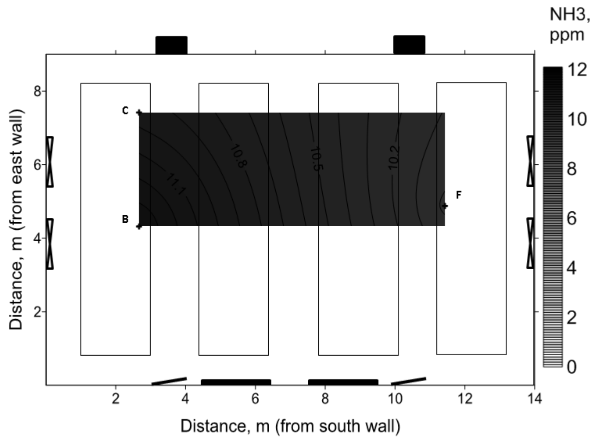

Figure D-28. Day 5 fixed area station mapping of NH_3 concentrations (pit fan on)

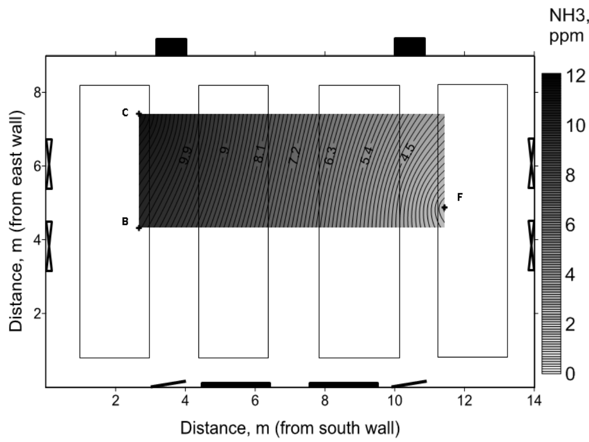

Figure D-29. Day 2 fixed area station mapping of NH_3 concentrations (pit fan off)

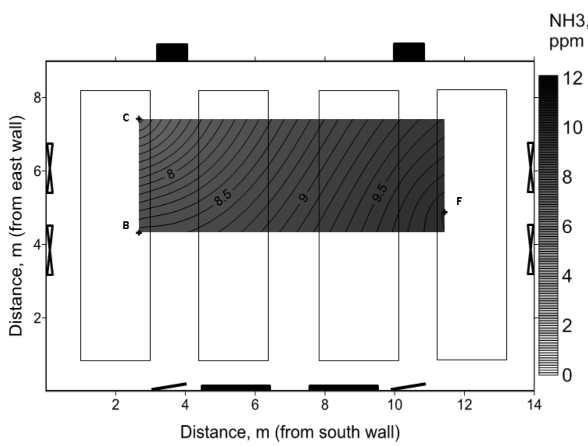

Figure D-30. Day 4 fixed area station mapping of NH_3 concentrations (pit fan off)

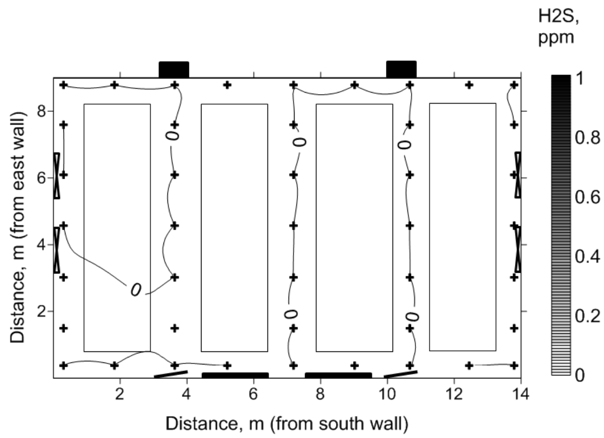

Figure D-31. Day 1 contaminant mapping of H_2S concentrations (pit fan on)

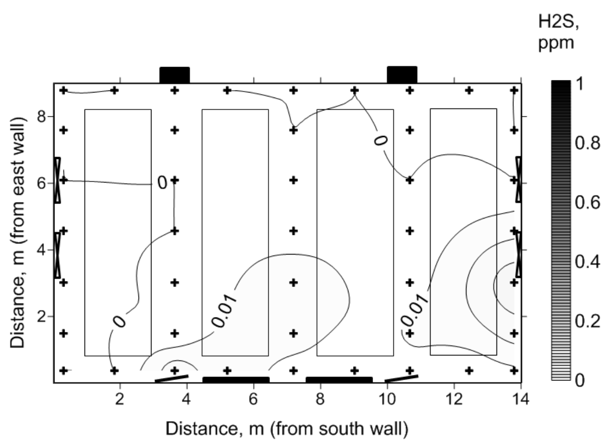

Figure D-32. Day 3 contaminant mapping of H_2S concentrations (pit fan on)

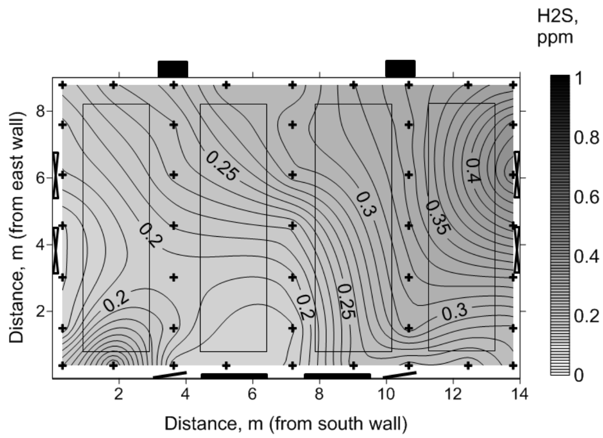

Figure D-33. Day 5 contaminant mapping of H_2S concentrations (pit fan on)

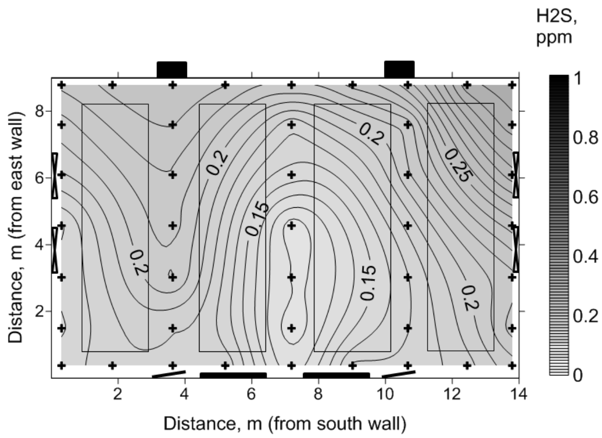

Figure D-34. Day 2 contaminant mapping of H_2S concentrations (pit fan off)

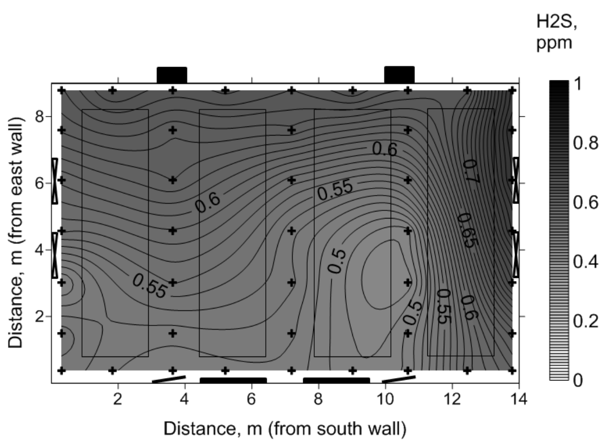

Figure D-35. Day 4 contaminant mapping of H_2S concentrations (pit fan off)

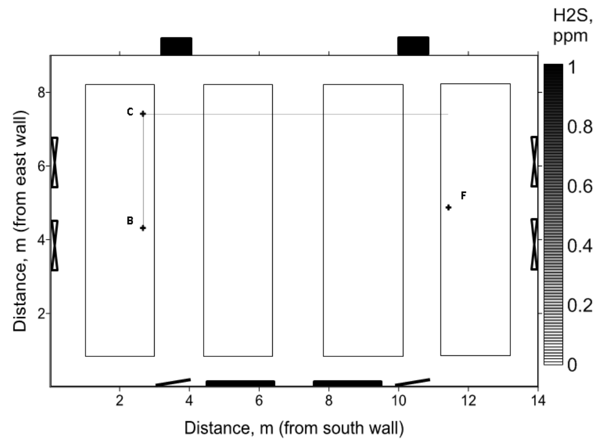

Figure D-36. Day 1 fixed area station mapping of H_2S concentrations (pit fan on)

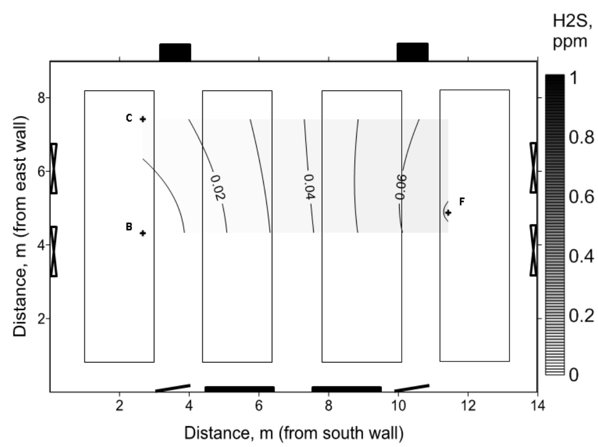

Figure D-37. Day 3 fixed area station mapping of H_2S concentrations (pit fan on)

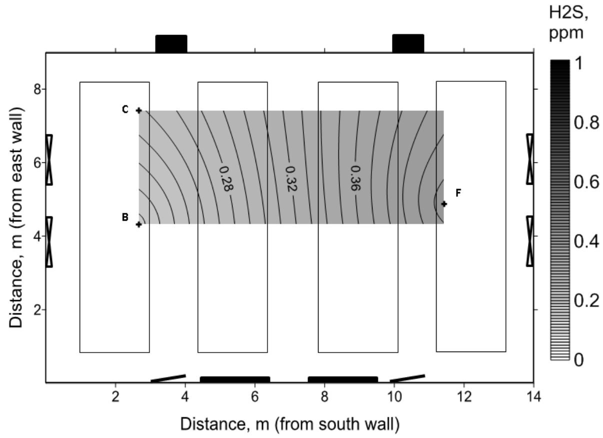

Figure D-38. Day 5 fixed area station mapping of H_2S concentrations (pit fan on)

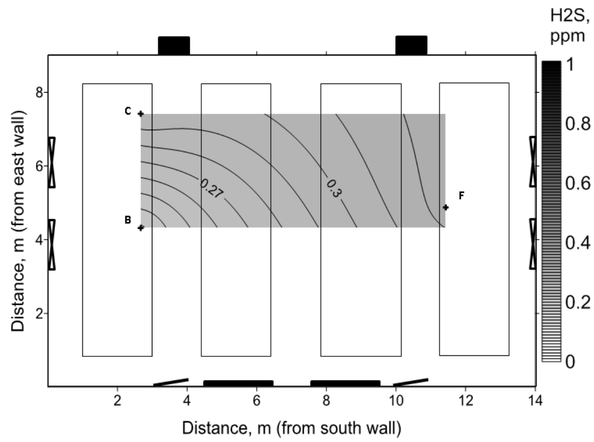

Figure D-39. Day 2 fixed area station mapping of H_2S concentrations (pit fan off)

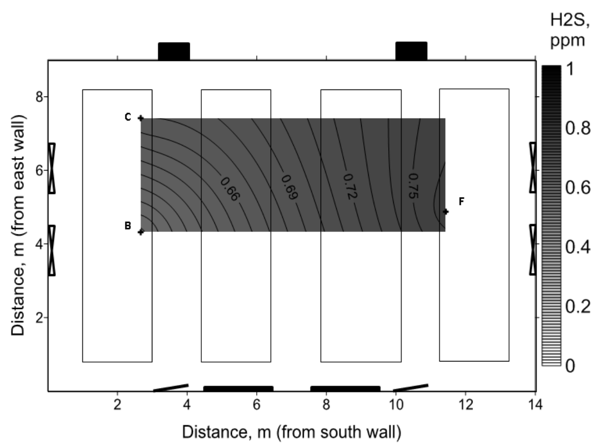

Figure D-40. Day 4 fixed area station mapping of H_2S concentrations (pit fan off)

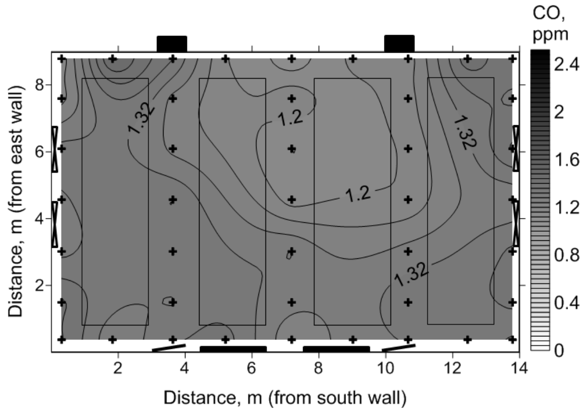

Figure D-41. Day 1 contaminant mapping of CO concentrations (pit fan on)

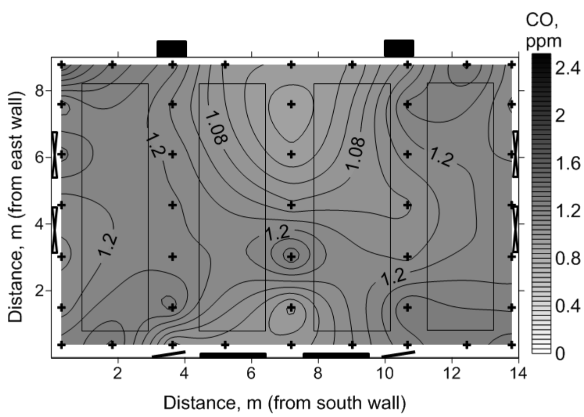

Figure D-42. Day 3 contaminant mapping of CO concentrations (pit fan on)

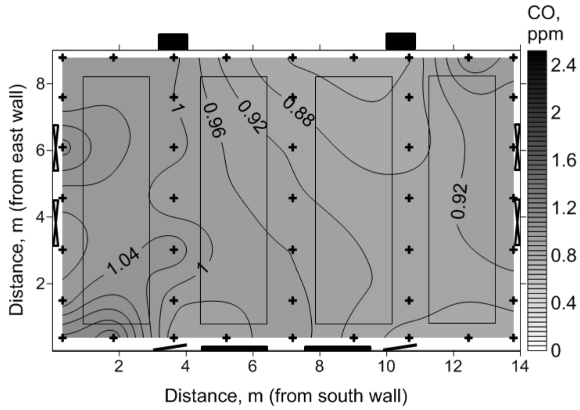

Figure D-43. Day 5 contaminant mapping of CO concentrations (pit fan on)

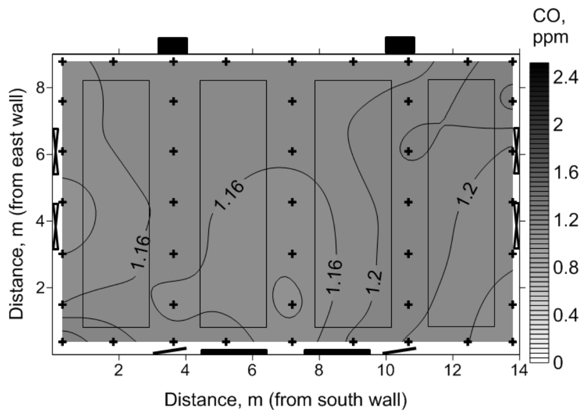

Figure D-44. Day 2 contaminant mapping of CO concentrations (pit fan off)

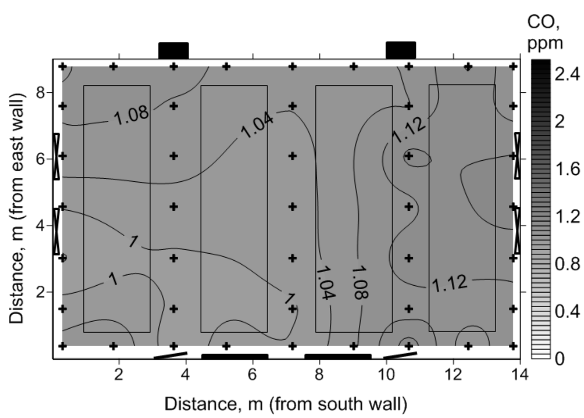

Figure D-45. Day 4 contaminant mapping of CO concentrations (pit fan off)

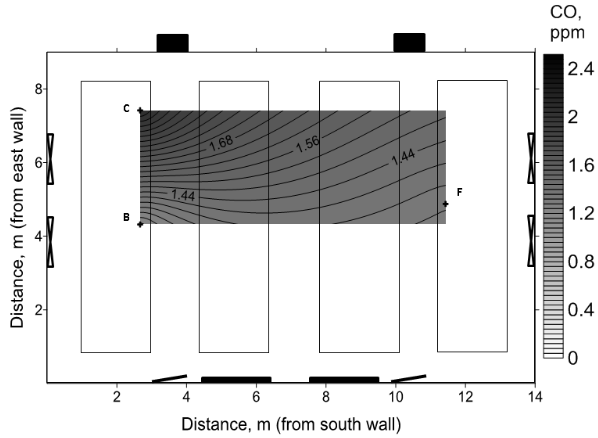

Figure D-46. Day 1 fixed area station mapping of CO concentrations (pit fan on)

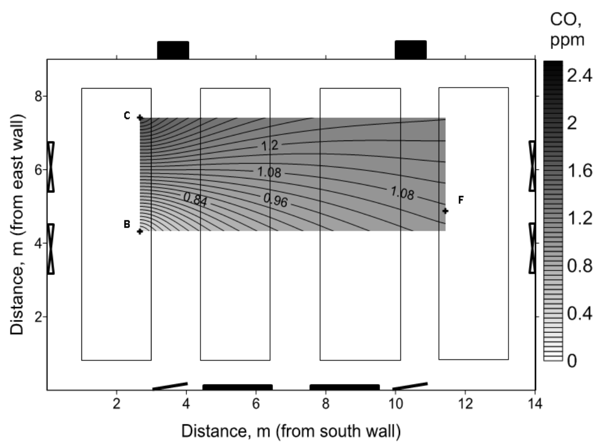

Figure D-47. Day 3 fixed area station mapping of CO concentrations (pit fan on)

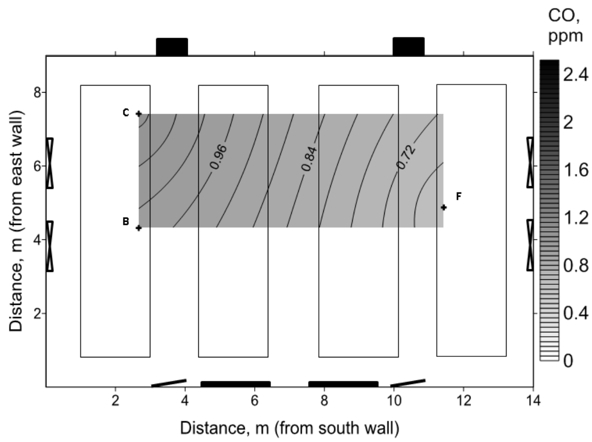

Figure D-48. Day 5 fixed area station mapping of CO concentrations (pit fan on)

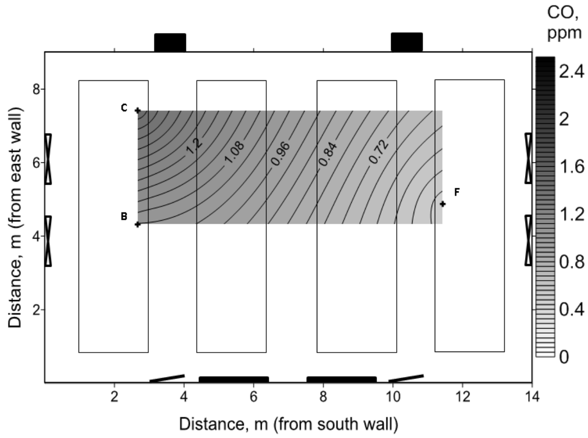

Figure D-49. Day 2 fixed area station mapping of CO concentrations (pit fan off)

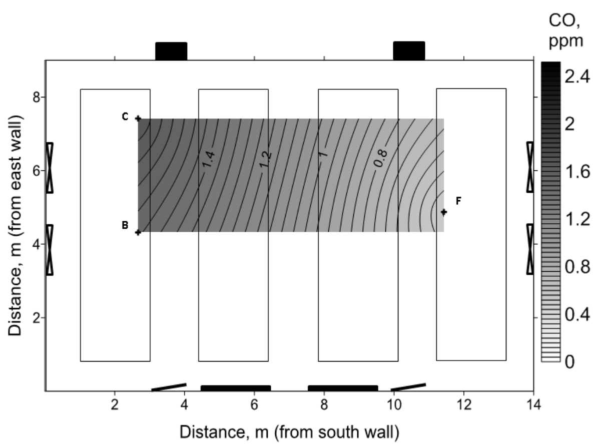

Figure D-50. Day 4 fixed area station mapping of CO concentrations (pit fan off)

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