EXPERIMENTAL MANURE HANDLING SYSTEMS FOR REDUCING AIRBORNE CONTAMINATION

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ABSTRACT

A laboratory was built at Prairie Swine Centre Inc. (PSCI) to study air quality in swine barns and its effect on pigs and people. The first focus of that research program was to design and test a manure handling system to control the air contamination from the excreta. The goal was to get close to zero air contamination from manure with these systems, in order to measure the contamination from other sources, and to also have a range of contamination levels for future health and productivity testing. Two manure handling systems were designed and tested: a washing gutter system with pressurized heated wash water periodically directed across the dunging area, and a washed inclined conveyor belt used directly as a dunging area.

Ammonia emissions were used as a measure of the air contamination originating from the excreta in two experimental chambers. Ammonia originates only from the manure and is released quickly from any manure (especially urine) in contact with the air. Both systems were tested with 30 kg pigs at running time intervals of 30, 60 and 120 minutes. Trials lasted one week, with three trials completed at each frequency. The average ammonia emissions from the washing gutter and the conveyor belt systems were 48.7 mg day^{-1} kg_{pig}^{-1} and 57.0 mg day^{-1} kg_{pig}^{-1}, respectively. Even though these emissions were 38% and 47% lower than previous observations from grower-finisher rooms with a pit plug design in the same swine building, both systems failed to give the desired “close-to-zero” contamination. This means another system will have to be found to totally eliminate air contamination from manure in the chambers when testing for the origin of the individual contaminants.

There were no differences at a statistically significant level ($P>0.05$) between the ammonia emissions from the two manure handling systems or the three frequencies tested. However, the washing gutter system was simpler and easier to run, and is recommended for future studies dealing with the effects of different ranges of air quality on pigs and people.

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1 INTRODUCTION

1.1 Background

The quality of air in confinement swine buildings is a growing concern as the impacts of poor air quality on the health of pigs and workers becomes better documented. An air quality laboratory has been built at the Prairie Swine Centre Inc. to study air quality in swine buildings and its effect on pigs and people. This study dealt with the design and testing of two manure handling systems for the laboratory. The goal was to get close to zero air contamination from manure with these systems, and to also have a range of contamination levels for future health and productivity testing.

This thesis is divided into five chapters. A literature review of issues relating to airborne contamination in swine buildings follows this background, then the hypothesis and the objectives of the research project. The second chapter describes the experimental facilities that were built. The experimental methods and equipment are described in the third chapter. Results of the trials are shown in the fourth chapter, and the conclusion and recommendations arising from the research work are presented in the fifth chapter.

1.2 Literature Review

1.2.1 Air Quality in Swine Buildings

Changes to barn design and management practices in the last 30 years have resulted in many improvements in swine building air quality, but health problems (especially respiratory health problems), continue to be identified among confinement barn workers. Their respiratory health has been related to the level of exposure to airborne contaminants (Donham, 1995). These contaminants consist of dusts, gases, and microorganisms often referred to as "bioaerosols".

It is more difficult to establish a relationship between air quality and pig performance. Bate et al. (1988) noted that while environmental parameters varied markedly, pig performance did not seem to be affected. De Boer et al. (1991) reviewed many studies and reported conflicting results, with some experiments finding environmental effects producing disease, and some finding that there was no effect on the animals. They concluded that the tolerances of swine for high levels of contamination are considerably greater than human tolerances, and consequently the design should ensure the air quality is suitable for people.

Dust in swine buildings came mainly from the feed, litter, fecal material, and animals (Maghirang et al., 1997). Gases originate from freshly deposited and stored manure, from the animals themselves, and from the feed (Hartung and Phillips, 1994). Bioaerosols including bacteria, endotoxins (cell-wall components of Gram-negative bacteria), fungi and yeasts (Seedorf et al., 1998), could originate with the animals, feed, or manure (Donham, 1995).

Hartung and Phillips (1994) found that the most common problem gases in swine confinement units were carbon dioxide (CO_2), ammonia (NH_3), hydrogen sulfide (H_2S), methane (CH_4), nitrous oxide (N_2O), and some trace gases (aldehydes, amines, aromatics, organic acids, and sulphur compounds). They noted that carbon dioxide was given off by the respiration of the animals, and to a small extent, by the decomposition of the manure. Hydrogen sulfide and methane were produced by the anaerobic decomposition of the stored manure, and methane could also come from the animals themselves. Ammonia was formed by bacterial and enzymatic breakdown of the nitrogenous compounds in the by-products, especially in the urine.

The air quality in a swine building directly affects the emissions from the unit, which in turn affected the environment, both locally and regionally (Groot Koerkamp et al., 1998).

1.2.2 Potential Control Methods

Many research articles stress that removing the manure quickly from the room is the only way to reduce the contamination in the air from the manure. O'Neill and Phillips (1991) noted that the main option to reduce odour production in livestock buildings was frequent removal of the by-products from the buildings. More recent research focused on the air quality rather than the odour, but the message was the same. Hartung and Phillips (1994) stated that reduction of harmful emissions from livestock units should begin with the housing and manure removal methods, and the feeding and management. They claimed the largest part of the gases originated from the animals' excreta, and showed that different types of manure removal affected the ammonia emissions. Replacing a fully slatted floor and long-term manure storage with partly slatted flooring reduced emissions by 20%. Adding a sloped floor under the slats from which the by-products are washed several times a day resulted in a further reduction, to 30% of the original emissions. Using a "basin and plug" method of removal of the flushing water resulted in a 70% reduction of ammonia emissions.

Usually, pigs will maintain a defined lying and dunging area within the pen. Whatson (1985) studied the dunging behaviour of pigs and concluded that the pigs choose a lying area, and generally choose not to dung in the lying area. Randall (1982) determined that a warmer lying area and a cooler dunging area would be an important factor in encouraging desirable behaviour. Aarnink et al. (1993) also found the placement of the feeder and drinker influenced the pigs' choice of dunging area. Adjustable placements of the feeder and drinker and the ventilation in these chambers may be advantageous to limit excrement outside of the dunging area.

Flushing gutters have been used to improve indoor air quality with some success in the past. One of the advantages of the flushing gutter was timely removal of the by-products, eliminating some of the potential for unwanted gases. Brodie (1975) also found that flushing reinforced the dunging behaviour and left the rest of the pen much cleaner. Hoeksma et al. (1993) noticed a large reduction in ammonia emissions with flushing gutters under slatted flooring. Their experimental units showed a 60%-70% reduction of ammonia emissions compared to the control unit with fully slatted flooring and 50%-60% compared to the control unit with partly slatted flooring. Hartung and Phillips (1994) reported that flushing systems remove the by-products more completely than scrapers or flow systems, and if flushing is done every half hour, ammonia production can be minimized. In dairy barns, research has found that flushing frequency and the amount and quality of the flushing water determined the amount of the reduction in ammonia emissions. Studies have found reduction levels of 14%-70% compared to partly slatted flooring (Kroodsma et al. 1993; Voorburg and Kroodsma 1992; Ogink and Kroodsma 1996). One of the major disadvantages of flushing gutters is the amount of flushing water that is used. However, for an experimental setup using only a few animals, the water usage is more acceptable than it would be under commercial conditions.

Another manure removal system that had potential to reduce air contamination is a sloped conveyer belt. Part of the reason there is a reduction in gases is the separation (right at the source) of liquid and solid by-products. Hartung and Phillips (1994) found that most of the ammonia produced from storage of manure is from the degradation of the urine, with smaller amounts coming from the breakdown of the faeces. They measured levels of ammonia emitted from stored bovine urine to be 135 times as much as from stored bovine faeces. Urease, which is an enzyme produced by microorganisms in the faeces, catalysed the degradation of the urea in the urine into ammonia (Elzing and Monteny, 1997). If the solid and liquid portions of the manure are kept separate, there will therefore be less production of ammonia than if they are combined. There are other advantages to separation, including the ability to fertilize fields more exactly (and perhaps reduce manure transportation costs) with the high-phosphorus portion and the high-nitrogen portion of the manure being stored separately (von Bernuth, 2001).

Von Bernuth (2001) studied a scraper system that separated the urine from the solids, taking advantage of the separation benefits. O'Neill and Phillips (1991) found that removal of only the liquid portion of swine by-products appeared to reduce odours. Svennerstedt (1999) recommended separation and rapid removal (particularly of the urine) as a measure to control ammonia emissions from dairy cattle housing. Voermans and Poppel (1993) showed the results of different scraper systems in pig housing, and found wide variations in the amount of improvement in the air quality in these units. The ammonia emissions were reduced up to 80% in one system, but some of the systems did not see much difference. They noted that if the floors in the units were not kept clean, there was a large emission from the dirty areas. These scrapers were all under slatted floors.

Kroodsma (1980) used synthetic netting to separate the solid and liquids under slatted floors. He noticed a reduction in odours with this system. The concentrations of the odorous compounds were reduced by 36%-70% (for individual components) compared to a liquid manure system. A group of people at different universities is studying different methods of removing by-products, including a scraper system that separates urine and an inclined conveyer belt (Humenik, 2002). There are also others working on conveyor systems to remove manure (van Kempen et al. 2003). All of these systems use slatted flooring above the mechanical system to protect the pigs from the machinery and the machinery from the pigs. No references were found that had used the conveyer belt without slatted flooring over it. Removing the slatted flooring over the conveyor belt would get the advantages of the timely removal of excreta without the disadvantages of having a dirty floor above it.

Arogo et al. (2001) noted that reducing the emitting area is one way to limit ammonia emissions. He suggested that replacing slatted flooring with sloped concrete could reduce ammonia volatilization up to 50% in dairy barns. Slatted flooring has much more surface area than solid flooring, and consequently a greater emitting area. Hoeksma et al. (1993) found about 20% more ammonia emissions from a fully slatted floor than a partly slatted floor.

1.2.3 Contribution of Each Source

Contributions from the animals themselves, their feed, their manure (both recently deposited and stored), and the incoming air, all combine to produce the air quality that is experienced in the unit (Hartung and Phillips, 1994). Thus, there is some understanding of what contaminants are in the air in a swine building, but it is unclear exactly where some of the contamination comes from. Hartung and Phillips (1994) and Gustafsson (1997) indicate a need to improve our knowledge of sources and quantities of contaminants.

1.2.4 Testing the Effectiveness of the Designs

Manure contributes dust, gases, and bioaerosols to the environment in swine buildings (Hartung and Phillips, 1994). There were some gases released from the freshly deposited manure, mainly odourous gases in small concentrations, and if the manure was stored for any length of time, other gases were released from the decomposition of the manure. These varied according to the components found in the slurry or manure, and also whether the decomposition happened in the presence of oxygen (Donham, 1988). If the manure was allowed to dry in the pen, there was also dust and bioaerosols released from the by-products (Takai and Pedersen, 2000).

Ammonia was one of the gases often found in the air in swine buildings. It was released very quickly by urine puddles, and over a longer time by the solid portion of the manure (Groot Koerkamp et al., 1998). The only other contributor to the ammonia in the air could be the animals themselves, and only one reference to this was found. Hartung and Phillips (1994) reported that part of the ammonia in the air was probably produced by the pigs, particularly those compounds that made up the species-specific odour. However, in another section of the same paper, they claimed all the ammonia came from the excreta. There is a possibility that flatulence in pigs would contribute to the ammonia levels, but as less than 1% of the gas in human flatulence could be ammonia (Lasser et al., 1975), the contribution is assumed to be minimal. If ammonia is primarily associated with excreta, it could be used as an indicator of the manure handling effectiveness at removing urine and faeces from the room air space.

1.3 Hypothesis

The general hypothesis of this research program was that by starting with a clean area, the source of the air contamination in commercially used swine housing could be quantified. The specific contribution of the feeding process, the manure handling system, and the presence of animals could be separated and measured. It was thought that experimental housing units could ultimately be designed where the individual processes produce no air contamination. A laboratory was built to test this general hypothesis.

This study deals with one part of the larger research program, designing and testing two manure handling systems for use in the laboratory. The hypothesis for this study was that flushing gutter and conveyor belt manure removal in swine production buildings could eliminate airborne contamination from manure using ammonia emissions from these buildings as the indicator for this source of contamination.

1.4 Objectives

The long-term goal of the larger research program was to develop practical building and equipment systems that would optimize the welfare of the animals and the health and safety of barn workers. As well, it was hoped these systems would minimize the contamination released from the building into the surrounding airspace.

The general objective of this research work was to evaluate experimental in-barn manure handling systems that could minimize airborne contamination from manure using ammonia emissions as the main contamination indicator. Specific objectives were: 1. To design and evaluate a flushing gutter manure handling system, and 2. To design and evaluate a conveyor belt manure handling system. Close to zero air contamination from the manure is needed in order to isolate the contamination coming from the feed and from the animals themselves. It was therefore hoped that one of these two systems could result in near zero manure-generated air contamination levels, as well as provide the opportunity for a range of contamination levels for health and productivity testing in future studies.

2 MATERIALS

2.1 Experimental chambers

2.1.1 Chambers

In a room in the grow/finish area at the PSCI Floral site, two experimental chambers were built with inside dimensions of 4.3 m x 3.7 m x 2.8 m high as shown in Figure 1 (also see Appendix 7.3). These chambers had concrete floors and 0.16 m thick concrete walls extending up 0.8 m. The remainder of the interior walls and ceilings were standard insulated 15 cm thick wood construction, with the interior finish being 1 cm plywood covered with well-sealed 1 mm stainless steel sheeting to reduce the potential of gas absorption. In each chamber, there was a large window (1.8 x 0.9 m) in one side wall, and a well-sealed door (2.0 x 0.9 m) in one end wall. A 4.9 x 3.1 m control/instrumentation chamber was also built inside the room to house the instrumentation and tools.

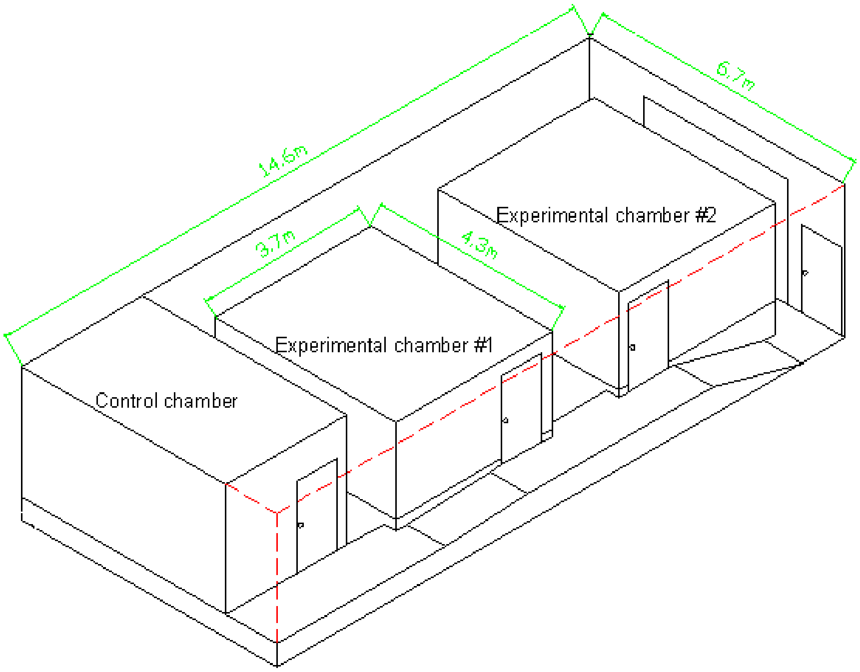

Figure 1 Layout of the experimental chambers.

2.1.2 Flooring and Penning

Plastic matrix flooring on fiberglass beams (Matrix Gold NR2424, Matrix Ag Inc., Calgary, Canada) that could be installed or removed in sections was used to make raised slatted floors 0.61 m above the concrete floor of the chamber (Fig. 2). Sections of this plastic flooring were removed in both chambers, allowing space for the washing gutter to be installed in one chamber and the inclined conveyor belt in the other. Plywood sheets (2 cm thick) covered by a 5 cm layer of concrete were set on supports on the slatted floors to produce sloped (8% grade) solid flooring in the areas of the pens not used for dunging. Penning was added to give each chamber the same amount of solid concrete flooring (2.13 x 2.13 m), and the same amount of dunging area (2.13 x 1.22 m) in the pens. These pens were sized for 10 grower pigs, providing each with 0.7 m^2 of floor space. This is more than the minimum 0.5 m^2 per grower pig recommended in Canadian Farm Buildings Handbook (Agriculture Canada, 1988) for solid floor pens for pigs under 45 kg.

Figure 2 Construction details in washing gutter chamber showing flooring and penning.

2.1.3 Water and Feed

Water was provided on one side of the dunging area in drinking cups. It was expected that wet flooring due to water spillage would encourage the pigs to use the area for excreta. A commercial feeder was installed in a gap in the penning on the solid concrete flooring and an effort was made to select a feed that would minimize dustiness (i.e. crumbles rather than mash feed), and therefore increase the precision of tests for the amount of dust produced by the manure handling system. The feeder and water placement could be adjusted as needed.

2.2 Manure handling systems

2.2.1 Flushing gutter

A variation of the traditional flushing gutter was used in this study. Pressurized water was used to allow effective washing of the dunging area using smaller quantities of water than traditional flushing systems. The dunging area in the flushing gutter system consisted of a 1.2 x 2.4 m metal frame table with 2 cm plywood holding 4 cm concrete as a table top (Figs. 3 and 4). Twelve nozzles (6 mm, brass 110˚ fan spray) were mounted (equally spaced) on a steel plate at the edge of the table top. These nozzles directed pressurized heated wash water parallel to the table top over the dunging area. The wash water came from the boiler supplying heated (to approximately 43°C) water to the barn, and was pressurized using a booster pump (Goulds Pumps 10GB20, ITT Industries, White Plains, NY, USA with a 2 cm Penn Flow Switch) to approximately 1.4 MPa.

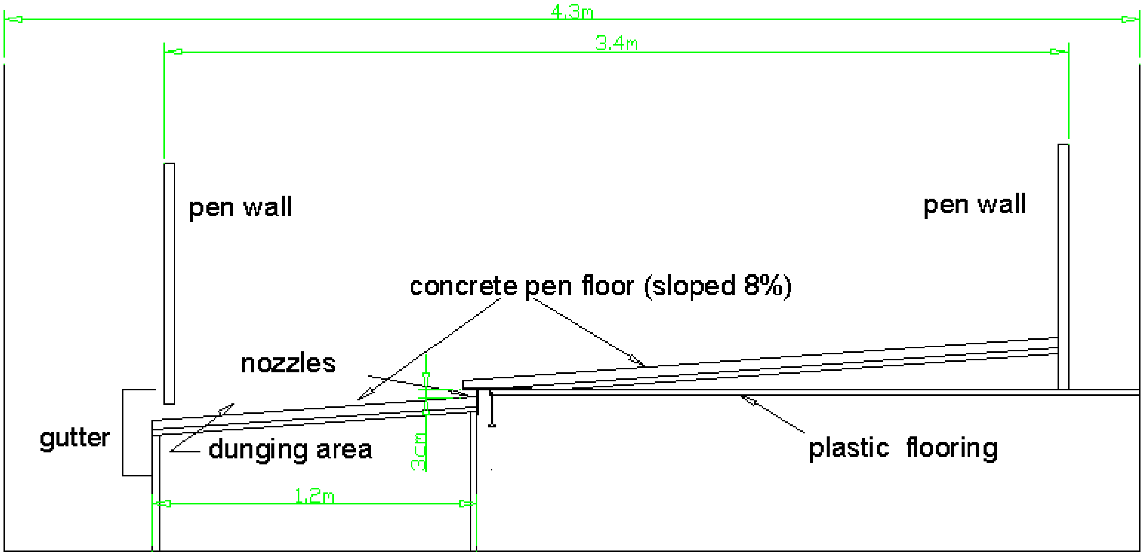

Figure 3 Drawing of washing gutter details.

a) Nozzles for the washing gutter b) Operation of the nozzles

Figure 4 Washing gutter used as a dunging area.

Four solenoid valves (24 VAC, 2 cm, nylon, normally closed), each controlling the water flow to three nozzles, were operated using a datalogger (Datataker DT 100, Data Electronics [Aust.] Pty. LTD., Rowville, Australia), and could be configured to deliver different amounts of water and different frequencies of flushes (Fig. 5). After some experimentation to find what worked well, the system was set up to open 6 nozzles for 30 seconds and then the remaining 6 nozzles for 30 seconds each time the dunging area was to be cleaned. The water flushed the by-products from the dunging area through a 4 cm gap under the pen wall into a 0.17 m x 0.14 m x 2.4 m long stainless steel gutter, which channeled the manure through a water trap (10 cm PVC P- trap) into the barn sewer system.

Figure 5 Solenoid valves in washing gutter chamber.

2.2.2 Conveyor belt

In the other experimental chamber, the 1.2 x 2.4 m custom-built conveyor belt (Univeyor Conveyors, Burnaby, BC, Canada) was used directly as the dunging area (Figs. 6 and 7). The conveyor belt could be configured to move at different timed intervals, controlled via a datalogger and the adjustable linear speed of the belt was extremely slow (0.05 – 0.25 m s^{-1}). For these trials, the belt speed was set to allow the soiled belting to be conveyed out of the dunging area in one minute (0.05 m s^{-1}) in order to have the same cleaning time as the washing gutter system. A 0.75 kW variable speed motor with an inverter controller (Industrial motor and Series 15P controller, Baldor Motors and Drives, Fort Smith, AK, USA) provided power to the conveyor belt. In preliminary testing, it was found that the controller did not tolerate pressure washing well, and was therefore mounted in an electrical box that could be sealed before washing the chamber. The belting was manufactured with a crescent pattern to make it less slippery for the pigs. The conveyor table had side pieces with triangular cross section added to hold the belt in a trough shape in order to channel all wastes to one end, as shown in Figure 6.

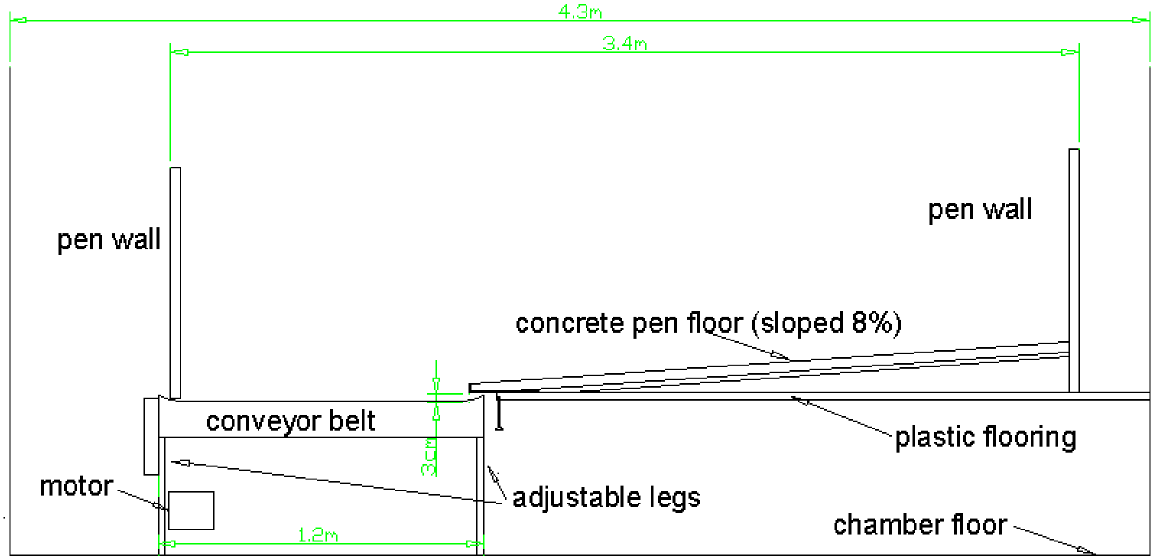

Figure 6 **Drawing of conveyor belt details.**

Figure 7 Pigs using the conveyor belt as a dunging area.

Adjustable legs were set to position the solid table of the conveyor belt at a 0.5% angle to allow liquids to flow off the head pulley end of the belt. As the belt moved, solids were scraped off using a rubber straightedge mounted on the underside of the 14 cm head pulley, the belting was washed, and clean belting was returned to the pen. Washing was done using water from the heated (approximately 43°C) pressurized (approximately 13 MPa) line supplying the pressure washing water to the barn. A valve (SS-63TF8-42VDC-3600 60 series valve c/w electric actuator, Swagelok, Solon, OH, USA), operated by a datalogger controlled the flow of water to three nozzles (6 mm brass 110˚ fan spray) that were positioned to wash the belting under the head pulley of the conveyor belt. The manure and wash water were collected in a 16 x 22 cm stainless steel gutter and channeled to the barn sewer system through a trap (8 cm PVC P-trap). Thus, the manure was removed quickly from the chamber and the soiled areas were washed. This was expected to eliminate most of the contamination resulting from the manure.

The pen wall had a 5 cm opening above one end of the belting to allow solid manure to be conveyed out of the pen. There was some concern that a pig could become trapped in this opening by the movement of the belting. An optical sensor (Omron Electronics LLC, Shaumburg, IL, USA) was installed to stop the belt if there was deflection of the pen wall above the opening, which would occur if a pig was dragged into this wall.

2.3 Ventilation

The ventilation system was separately controlled in two different zones: the room and the chambers. A 0.8 m diameter centrifugal fan (Delhi BIDI-20, Delhi Industries Inc., Delhi, ON, Canada) created a negative pressure in the room and forced outside air from the eaves of the building through the attic and into the room volume (Fig. 8). A 10 kW electric heater (Chromalox, Dimplex North America Ltd., Cambridge, ON, Canada) and a 17.6 kW air conditioning unit (Raka-060 CAZ, Setra Systems, Boxborough, MA, USA), provided the pre-conditioning of the room air before it was directed to each chamber. The centrifugal fan was controlled by the static pressure difference before and after the fan. This was set at 60 Pa for this experiment.

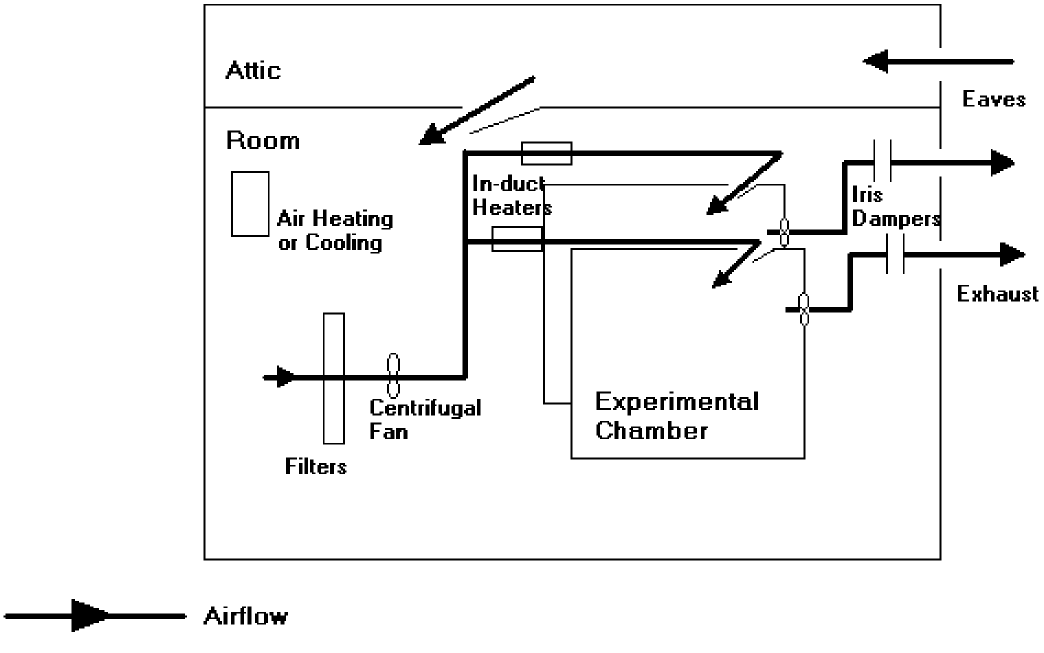

Figure 8 Ventilation flow diagram.

The room air then passed through a filtration unit (Circul-Aire USA-H204-B, Dectron International, Roswell, GA, USA), and a tee in the ducting directed the air to the two chambers, passing two 2 kW in-duct heaters (Thermolec, Montréal, Canada) (Fig. 9). One controller (Rapid Controller, Del-Air Systems Inc., Humboldt, SK, Canada) controlled the in-duct heaters, the exhaust fans in the chambers (H18, Del-Air Systems Inc., Humboldt, SK, Canada), and the actuated inlets in the chambers (CV1 C.C. Inlet with actuator assembly, Del-Air Systems Inc., Humboldt, SK, Canada), based on a temperature setting of 18°C in the chambers and a 30% minimum fan speed. Another identical controller controlled the 10 kW heater in the room, the exhaust fan in the control chamber and the inlets from the attic to the room, based on a 15°C temperature setting in the room.

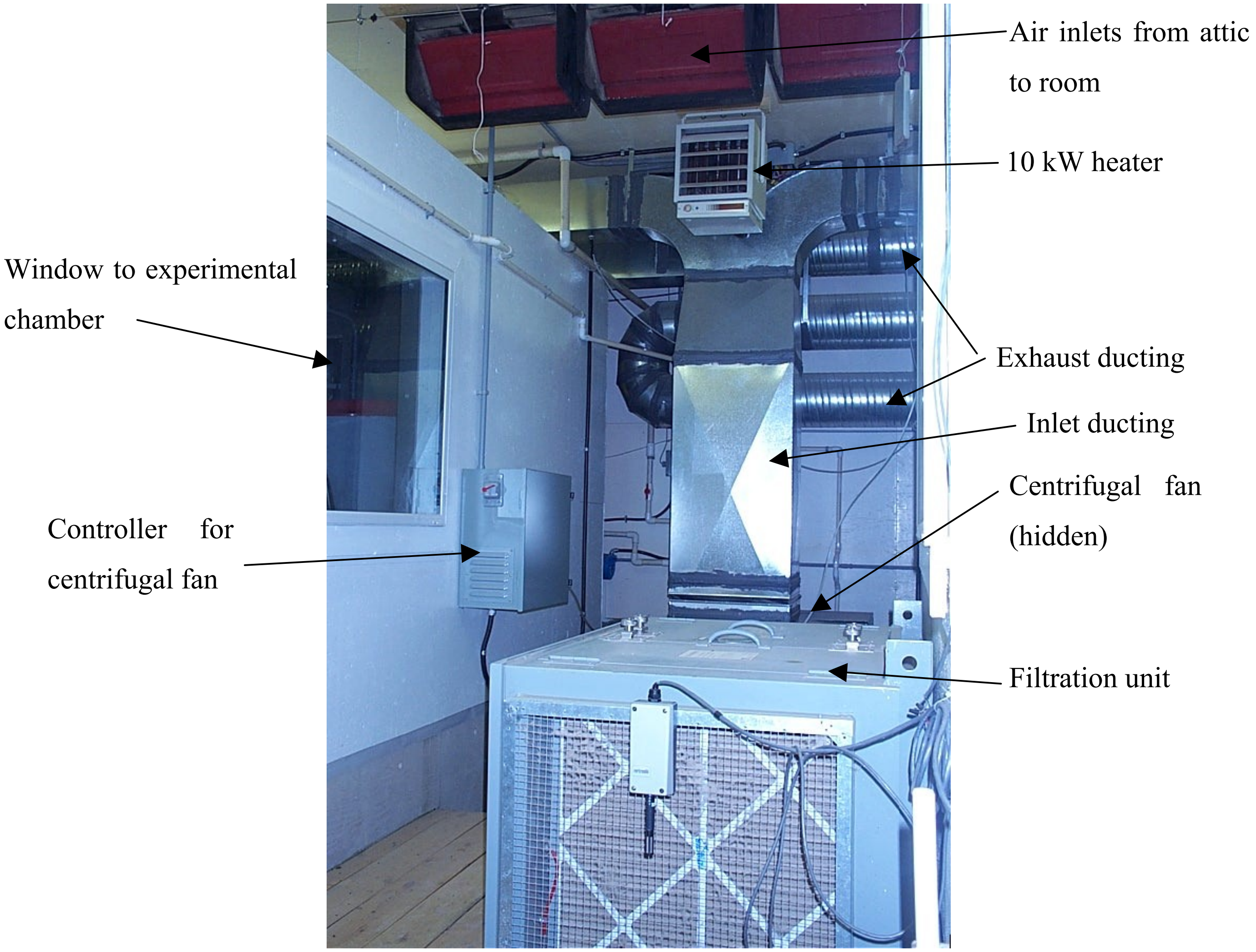

Figure 9 Photograph of some components of the ventilation system, showing the filtration unit, the 10kW heater, inlets from the attic to the room, ducting, and the controller for the centrifugal fan on the wall near the window of one chamber.

3 EXPERIMENTAL DESIGN

3.1 Methodology

The two experimental manure handling systems were tested at three frequencies of operation. Hartung and Phillips (1994) suggested that gutters be flushed every half hour in order to minimize the ammonia, so this was the starting point for the study. In addition to running the systems every half hour, trials were completed with the manure systems running every hour and every two hours, in an effort to have a range of levels of contamination in the air from the manure for health and productivity testing. Three trials were done at each frequency of operation, with the two chambers running at the same frequency in a random arrangement of the nine trials.

The manure handling systems in the chambers were programmed to run at the frequency required for the trial, and then 10 pigs (with an average weight between 25 and 35 kg) were added to the chambers in a group and given time to learn to dung only in the appropriate areas (which took from one to six days). The pigs were then removed long enough to thoroughly wash the chambers, and then were returned to the pens.

The air quality in the chambers was monitored for the following week. Data were collected for the ammonia and carbon dioxide levels at the air inlet and exhaust in order to determine ammonia emission levels. Ventilation rates (also needed for ammonia emissions) were determined using static pressure readings across an iris damper in the exhaust ducting from each chamber. Dust levels (on day 4 or 5 of the trial) in the chambers were measured as a secondary measure of the effectiveness of the manure handling system at eliminating the contamination from the manure. (Dust in the chambers came from the feed and animals as well as the manure, so ammonia was thought to be a better indicator and only ammonia was used in the statistical analysis.) Data on temperature and relative humidity of the air entering and leaving the chambers were collected in order to characterize the air flows.

Average ammonia emission levels for the two chambers in each trial were calculated and used to compare the efficacy of the two manure handling systems. The experiment was designed as a split-plot study, with the trials being the whole plots, the manure handling systems being the sub-plots and average ammonia emissions for the week being the dependent variable. An analysis of variance was performed using SAS (V8 version, 1999, SAS Institute Inc., Cary, NC USA), and a 5% probability level was selected to test for statistical differences between treatments.

3.2 Animals

The animals in the chambers were managed using standard operating procedure (SOP) for the Prairie Swine Centre Inc. Floral barn. This involved weighing animals before they entered the rooms and again when the trial ended, and using these weights to set chamber temperatures. Average daily gains were calculated from these weights to compare to typical values for the barn. Reduced nocturnal lighting was part of the SOP, as were reactions to animal health concerns. No animals had to be removed from the room before the rest of the group, and no animals died while in the chambers.

3.3 Instrumentation and Calculations

3.3.1 Ammonia and carbon dioxide concentrations

Ammonia concentrations were monitored in order to calculate ammonia emissions from the chambers, which were then used to evaluate the efficacy of the two manure handling systems. The carbon dioxide levels were monitored to provide a secondary way to estimate ventilation rates. Ammonia (NH_3) and carbon dioxide (CO_2) concentrations were measured at the air inlet and exhaust of each chamber using infrared analysers (ammonia analyser: Chillgard RT refrigerant monitor, MSA

Canada, Edmonton, Canada, accuracy ± 2 ppm; and carbon dioxide analyser: Guardian Plus, Topac, Hingham, MA, USA, accuracy ± 60 ppm).

The inlet and exhaust concentrations for each chamber could not be measured simultaneously, as the same analyser was used to measure all the sampling locations. Therefore, the exhaust air was sampled immediately after the inlet of the same chamber, in order to have samples as close in time to each other as possible. The average difference between the inlet and the exhaust concentrations was considered a good representation of the ammonia added to the chamber during the total sampling time of 22 minutes (Fig. 10).

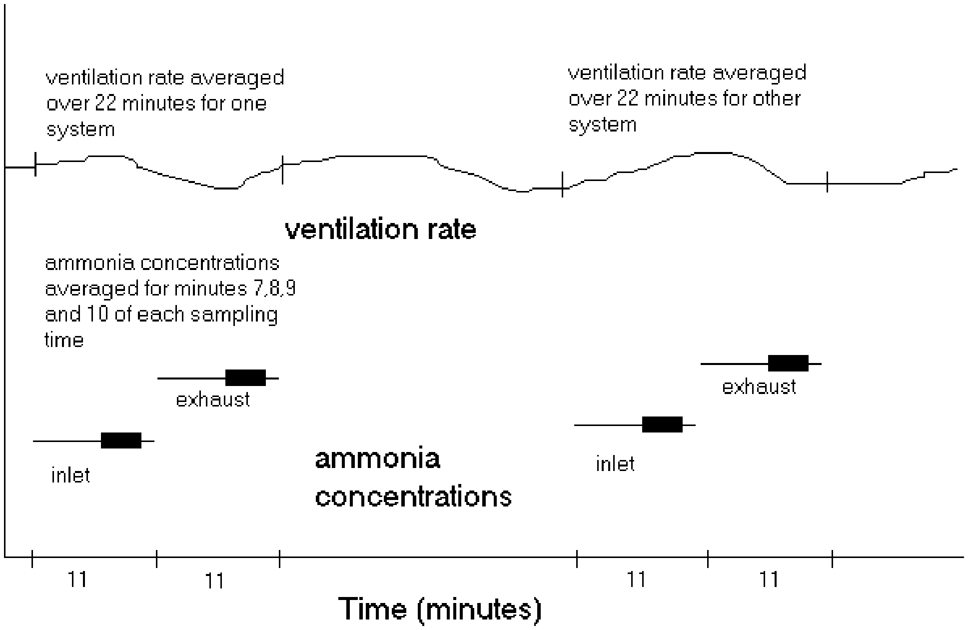

Figure 10 Ventilation and ammonia concentration sampling timeline.

A 6.4 mm diameter Teflon tubing line was installed for each sampling location and each line was connected to a 3-way solenoid valve in the control chamber (Fig. 11). The sampling lines were contained within two 5.1-cm diameter polyvinyl chloride (PVC) pipes that linked the experimental chambers and the control chamber. A heater and a fan in the control chamber forced heated air through the PVC pipes, keeping the temperature in the pipes above the room temperature to prevent condensation in the Teflon tubing.

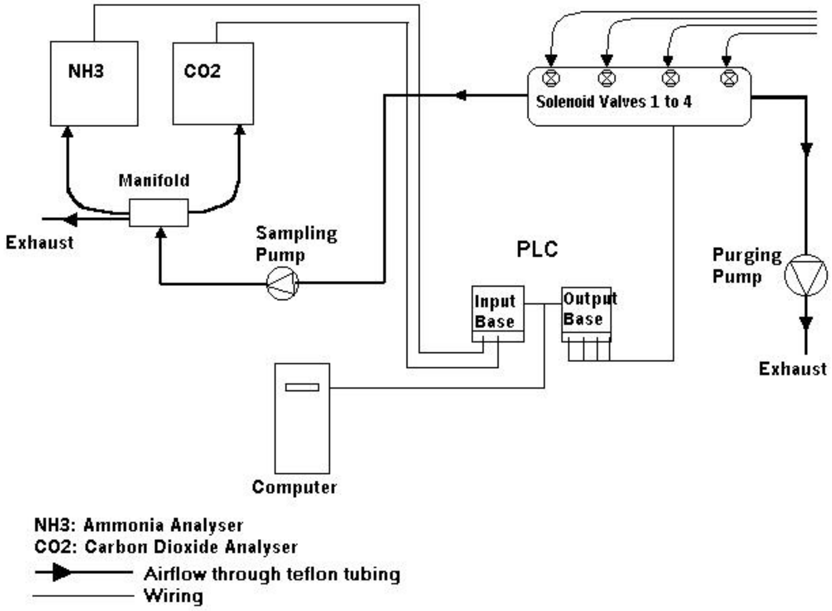

Figure 11 Flow diagram showing airflow and information flow.

Dust filters installed on the inlet end of the Teflon tubing protected the analysers from particulate contamination and damage, and these were changed at least weekly. The solenoid valves were activated one at a time by the output base of a Programmable Logic Controller (PLC) control system (model Modicon 171 CCS 760 00, Sceptre Controls Ltd, Regina, Canada) programmed with a computer, thus allowing the analysers to measure one sampling location after the other.

A sampling pump (Dia-Vac B01310TC5, Air Dimensions Inc., Deerfield Beach, FL, USA) drew air through the open solenoid valve from the sampling location into a pressure-equalizing manifold at a rate of 3 L min^{-1}, which then provided the air to the analysers. The small amount of excess air provided to the manifold was exhausted to the outdoors. While the air in one line was being analysed, a purging pump (Dia-Vac M01310TC5, Air Dimensions Inc., Deerfield Beach, FL, USA) drew air at a rate of 1 L min^{-1} through each of the other lines to reduce the time needed for the sample in the manifold to reflect current conditions at the sampling location.

Each analyser produced a 4 – 20 mA signal proportional to the gas concentration. This signal was read by the input base of the PLC, and transmitted to a computer in the control chamber, which converted the signal to a gas concentration. A Visual Basic program recorded the gas concentrations every second, then calculated and saved the average for every minute, along with the open valve number and the time. Each valve was activated for 11 minutes at a time, to allow time for the air provided to the analysers to be representative of the conditions at the inlet to that sampling line (Fig.10). An average of the four readings from minutes seven to ten was used as the average concentration for that eleven minute period. With four lines to sample, this meant that each line was sampled every 44 minutes in the first trial. Before the second trial started, another experiment also began using the analysers and the frequency of testing each line changed to once every 83 minutes for the remainder of the trials.

3.3.2 Ventilation rates

Ventilation rates were estimated by installing one iris damper (Continental Fan Manufacturing Inc., Buffalo, NY, USA, accuracy ± 5%) in the exhaust ducting of each chamber, and measuring the pressure difference across the damper using a pressure transducer (Setra 264, Setra Systems, Boxborough, MA, USA). The pressure transducer produced a 0-5 VDC signal corresponding to a 0 to 249 Pa pressure reading. A datalogger read and recorded these signals every minute during each trial. An average reading was calculated for each 22 minute period that the analysers were monitoring ammonia and carbon dioxide concentrations for that chamber. This value was used as to calculate the ventilation rate during that time using equation 3.1 as follows:

$$Q = k \times \sqrt{\frac{SP}{5000}} \times 0.471934 \times 0.001 \tag{3.1}$$

Where:

Q = ventilation rate ($m^3\ s^{-1}$)

k = constant which depends on the setting of the iris damper. This constant is 739 in the washing gutter chamber and 518 in the conveyor belt chamber for these trials (given by manufacturer).

SP = static pressure transducer reading (in mV), which needs to be divided by 5000 to convert it to inches of water

The other constants are to convert the units from cfm into the units desired for the ventilation rate (0.471934 L s^{-1} / cfm^{-} * 0.001 m^3 / L).

The fans, when running at their maximum speed (usually just after a cleaning event), occasionally would move enough air through the iris dampers to cause the transducers to go beyond their normal range and produce unusable data. This happened frequently with the washing gutter chamber in the test trials done before data were being collected, so the iris damper in that chamber's exhaust ducting was adjusted. However, the overloading continued to happen occasionally, and got more frequent as time went on.

The pressure transducer was connected to small (approximately 3 mm ID) holes in the exhaust ducting before and after the iris damper. These holes occasionally plugged, and needed to be periodically cleaned.

3.3.3 Ammonia Emissions

Ammonia emissions were used to measure the efficacy of the two manure handling systems. The ammonia emissions were calculated for each sampling time period using equation 3.2 as follows:

$$AE = \frac{\rho_a \times (AC_o - AC_i) \times Q \times 86.4}{W_{pig}} \tag{3.2}$$

Where:

AE = average ammonia emission rate for one chamber during one sampling event (g d^{-1} kg_{pig}^{-1})

ρ_a = density of ammonia (mg mL^{-1}) – considered constant at 0.7105 mg NH_3 mL^{-1}

AC_o = average ammonia concentration at the exhaust fan during the sampling event (ppm)

AC_i = average ammonia concentration at the chamber inlet during the sampling event (ppm)

Q = average chamber ventilation rate during the sampling event (m^3 s^{-1})

W_{pig} = average total pig mass for the chamber during the corresponding week (kg)

In equation 3.2, ammonia concentrations at the inlet and exhaust fan are shown in ppm on a volume basis (ppm = mL m^{-3}). The constant 86.4 is used to change the units from mg s^{-1} to g day^{-1} as follows:

$$AE\left(\frac{g}{day}\right) = emissions\left(\frac{mg}{s}\right) \times \frac{g}{1000mg} \times 86400\left(\frac{s}{day}\right) \tag{3.3}$$

The density of ammonia used in equation 3.2 was considered constant at 0.7105 mg NH_3 mL^{-1}. The density of ammonia varies with temperature, and is 0.7708 mg NH_3 mL^{-1} at 0°C and 0.6894 mg NH_3 mL^{-1} at 27°C (Cheminfo 2000; Incropera and Dewitt 2002). By interpolation, the density of ammonia at 20°C is 0.7105 mg NH_3 mL^{-1}, and this value was used for these calculations.

The average ammonia concentrations at the inlet and exhaust were considered representative of conditions during the 22 minutes that conditions in that chamber were being tested. Average ventilation rates from the chamber were calculated for the same 22 minute period, and these values were used to calculate average ammonia emissions during each sampling event. The ammonia emission values were averaged for each day, and then a daily average for each week was calculated.

3.3.4 Temperature and relative humidity

The temperature and relative humidity of the air entering the rooms (before the filter) and leaving the rooms (at the exhaust fans) were monitored using thermocouples (type T; accuracy ± 0.5°C) and humidity sensors (Rotronic M22W XMTR, Huntington, NY, USA; accuracy: ± 0.5% RH + 1.5% of reading; and ± 0.3°C). A datalogger was used to record the temperatures and relative humidity data every minute during each trial, and this was downloaded to the computer network of the research station once each day.

Using standard procedure for the production rooms of the barn, temperature set points were established using the average weight of the pigs entering the chambers. Pigs were selected to achieve the same average starting weights in both chambers, hence the temperature set point (18.0°C in most trials) was also identical for both chambers. For ease of experimental procedure, the temperature set point remained constant over the one week trial.

3.3.5 Water usage

A water meter (Model C700I, ABB Water Meters, Inc. Ocala, FL, USA) was installed in the water supply leading to the washing gutter. This meter was calibrated before the start of the experiment. The reading on the meter was recorded at the beginning and end of one 24 hour period each time there were animals in the room.

3.3.6 Dust Measurements

Dust measurements were taken from the two experimental chambers just before 10am on day 3, 4 and 5 of each trial as a secondary indicator of the effectiveness of the manure handling system. A hand-held laser particle counter (Model ABACUS 301, Particle Measuring Systems Inc., Boulder, CO, USA) was used to measure the number of dust particles in a sample of air in the chamber near the exhaust fans of both experimental chambers. The sampling time was one minute and the sampling rate was 2.83 L min^{-1}. The particle counter measured the diameter of the particles, and separated the counts into four size ranges: 0.3 – 0.5 μm, 0.5 – 1.0 μm, 1.0 – 5.0 μm and particles with a diameter greater than 5.0 μm.

While much of the dust will have come from the feed in each chamber, the chambers were treated the same (if feed was added in one chamber, it was also added in the other chamber), so differences in the dust levels should reflect differences in the manure handling systems' ability to reduce the particulate contamination in the air.

3.3.7 Data acquisition

Data were downloaded from the datalogger every day during the recording week, and stored on the hard drive of the computer and also on the computer network of the research station. The ammonia and carbon dioxide data were also stored on the computer network once a day.

3.3.8 Calibration of instruments

Calibrations were done on the thermocouples and the humidity sensors on day one, day four and the last day of each trial. There was little change in the calibration of the instruments during the first two weeks, so calibration frequency was reduced to once during each trial for the remainder of the experiment. This was done using a psychrometer (Cole-Parmer 3312-40, Cole-Parmer Instrument Company, Vernon Hills, IL, USA) to check the relative humidity readings, and a thermometer (Cole-

Parmer 93909-10, Cole-Parmer Instrument Company, Vernon Hills, IL, USA accuracy 0.5°C) in a water bath to check the temperature readings. The static pressure readings from pressure transducers connected to the iris dampers were also compared to inclined liquid manometer readings (Dwyer Instruments Inc., Michigan City, IND, USA accuracy ± 5 Pa) at those times.

Both gas analysers were calibrated with reference gases three times a week at the start of the experiment (Monday, Wednesday, Friday). Because there was some drift of the zero on the ammonia analyser (it read zero reference gas slightly differently after some time had elapsed), it was calibrated every day thereafter (except for 3 occasions), and the zero adjusted if it had changed more than 1 ppm from the previous reading. If the drift of the analyser was greater than 2 ppm, the values for the ammonia readings for the time since the last calibration were adjusted, assuming a linear drift over that time span. Because the exhaust and inlet concentrations were measured with the same analyser, the emissions (which are calculated using exhaust concentration – inlet concentration) should not be affected by any drifting of the zero of the analyser.

To check for leaks in the lines and to verify that the air sampling system was working as intended, zero and ammonia span gas were introduced into the sampling tubing of each of the chambers (once at the entrance to the washing gutter exhaust line and once at the entrance to the conveyor belt exhaust line) (see Appendix 7.2). The analyser readings were within 4% of the expected readings with the calibration gases (using a zero gas and a span gas around 160 ppm), and were within the accuracy of the analyser (± 2 ppm and ± 10% of readings over 50 ppm). This suggests that the sampling system is air tight and worked well at providing a representative sample of air to the analysers.

The carbon dioxide analyser remained very stable, and was calibrated once each trial after the first trial. The zero gas for both analysers was air (21% oxygen (O_2) in nitrogen (N_2)). Span gas for the ammonia analyser was 7500 ppm of pentane

(C_5H_{12}) in nitrogen (N_2). Span gas for the carbon dioxide analyser was 2400 ppm carbon dioxide (CO_2) in nitrogen (N_2). The entire system for gas collection and measurement (analysers, solenoid valves and Teflon lines) was maintained at a temperature above the chamber temperature to avoid possible condensation in the system and lines. Condensation could affect ammonia (NH_3) readings because ammonia is soluble in water and condensation could also damage the analysers.

4 RESULTS AND DISCUSSION

4.1 Ammonia and Carbon Dioxide Concentrations

Data from the April 12 – 19 period are representative of that collected during all the trials and will be used as an illustration (Fig. 12), indicating ammonia was being added to the air within each chamber. The ammonia concentration at the exhaust fan averaged 1.7 ppm above the inlet concentration in the washing gutter chamber, and 2.3 ppm in the conveyor belt chamber over all the trials completed. The first objective of this experiment was to have zero contamination in the air from the manure, and this would have been indicated by the exhaust and inlet ammonia concentrations being the same in that chamber.

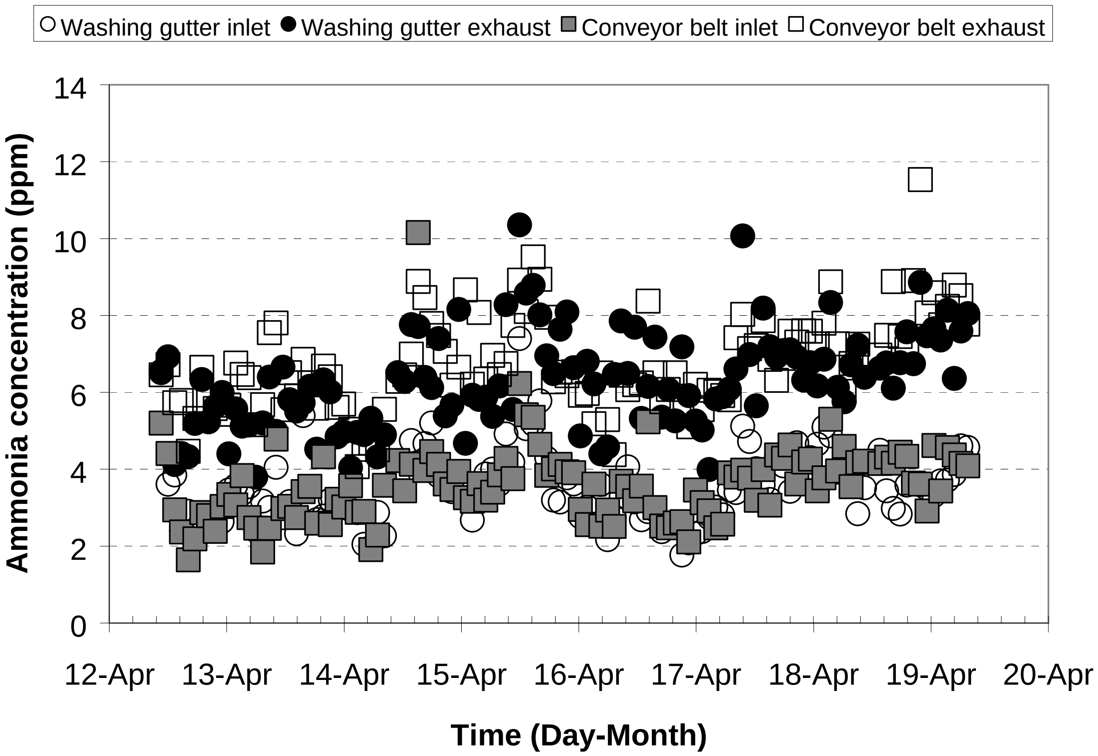

Figure 12 Ammonia concentrations in inlet and exhaust air in experimental chambers from April 12 – 19, 2004.

4.2 Ventilation Rates

The ventilation rates in the two chambers were not identical for the same period (Fig. 13) but they can be considered very similar to compare room emissions. The average ventilation rate was higher in the washing gutter chamber than in the conveyor belt chamber. The ventilation rates were controlled to maintain constant and equal temperatures in the two chambers. The air temperature was affected by the warm washing water to a greater extent in the chamber with the washing gutter. The conveyor belt washing was done within the gutter that removed the liquids, and this limited the exposure of the air in that chamber to the warm wash water.

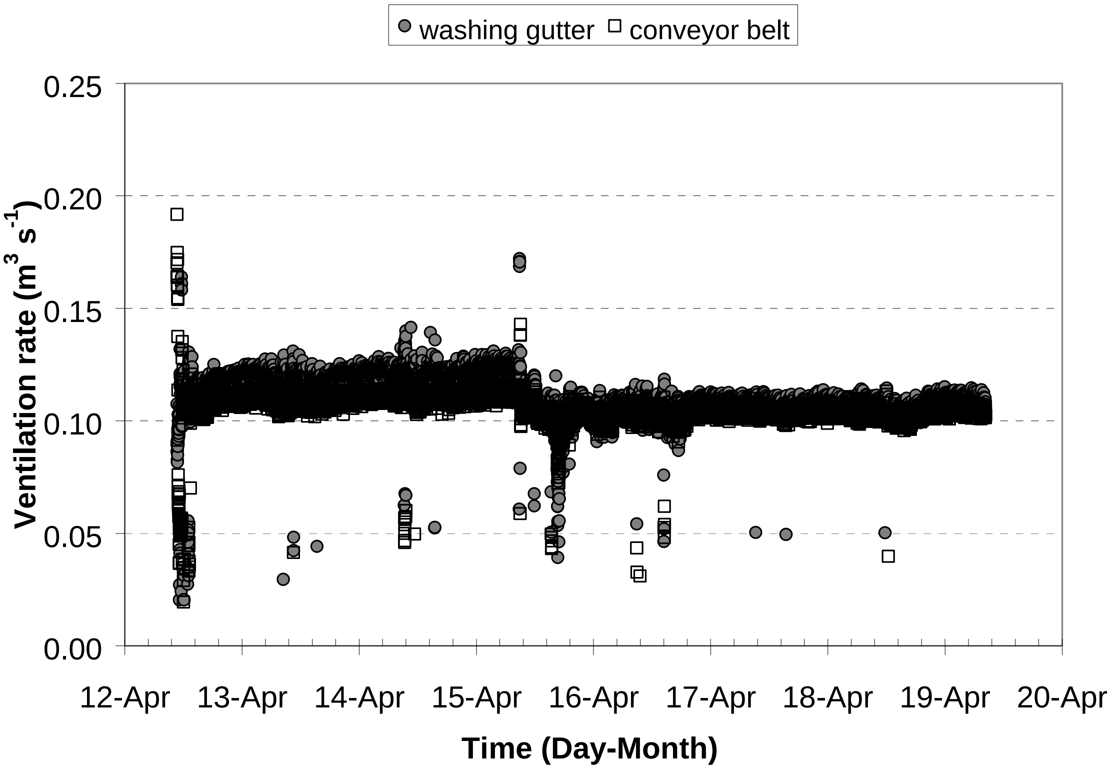

Figure 13 Ventilation rates in experimental chambers from April 12 - 19, 2004

Some problems were encountered with the ventilation systems. There were times when the exhaust fans were operating at maximum speed with the in-line heaters also working, which indicated a problem with the system. These problems grew more frequent as time went on, and resetting the controllers did not totally remedy the situation. These problems will have to be further investigated before completing future experiments.

4.3 Ammonia Emissions

Ammonia emissions from both chambers for the April 12 to 19-week are shown in Fig. 14. This week produced the highest average weekly values for ammonia emissions for both the washing gutter system and the conveyor belt system. The ammonia emissions trends are the same in the weeks with the lowest average weekly values (Fig. 15 and Fig. 16). Typically, ammonia emissions from the chamber with the washing gutter were slightly lower than for the chamber with the conveyor belt system. The ammonia emissions were also expressed as a function of the weight of pigs in the chamber in order to make comparisons with other trials and with the values found in the literature (Table 1). For all trials combined, the average ammonia emissions from the washing gutter system were 48.7 mg day^{-1} kg$_{pig}^{-1}$ (24.4 g day^{-1} animal unit^{-1} where an animal unit is defined as 500 kg live weight), and from the conveyor belt system were 57.0 mg day^{-1} kg$_{pig}^{-1}$ (28.5 g day^{-1} animal unit^{-1}). Previous experiments in the same research facility with the same size of pigs reported average ammonia emissions of 46 g day^{-1} animal unit^{-1} (Payeur, 2003). On average, ammonia emissions from the rooms equipped with the washing gutter and conveyor belt systems corresponded to 53% and 62% of those baseline emissions, respectively.

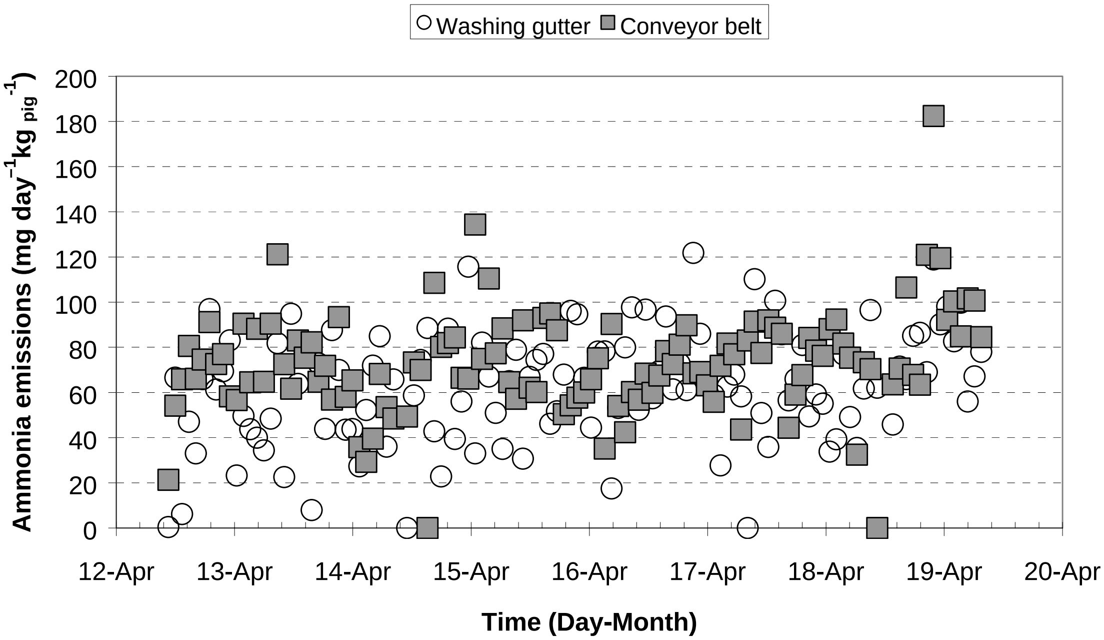

Figure 14 Ammonia emissions from experimental chambers from April 12 – 19, 2004.

Table 1 Average ammonia emissions from the chambers in each trial.

Date	Frequency (hours	Emissions (mg day^{-1} kg^{-1})		Standard Deviation (mg day^{-1} kg^{-1})	
		Washing gutter	Conveyor Belt	Washing gutter	Conveyor Belt
17-Feb	2	30.2	58.7	8.8	14.3
12-Apr	2	63.9	74.1	9.6	11.2
20-Apr	2	60.8	51.1	5.6	6.5
4-Mar	1	46.2	73.0	6.1	10.0
20-Mar	1	44.2	57.2	9.7	9.9
8-May	1	54.3	50.7	14.0	13.2
12-Mar	0.5	39.6	38.8	8.3	4.2
3-Apr	0.5	54.5	45.7	32.1	16.3
19-May	0.5	44.5	59.8	20.5	25.3

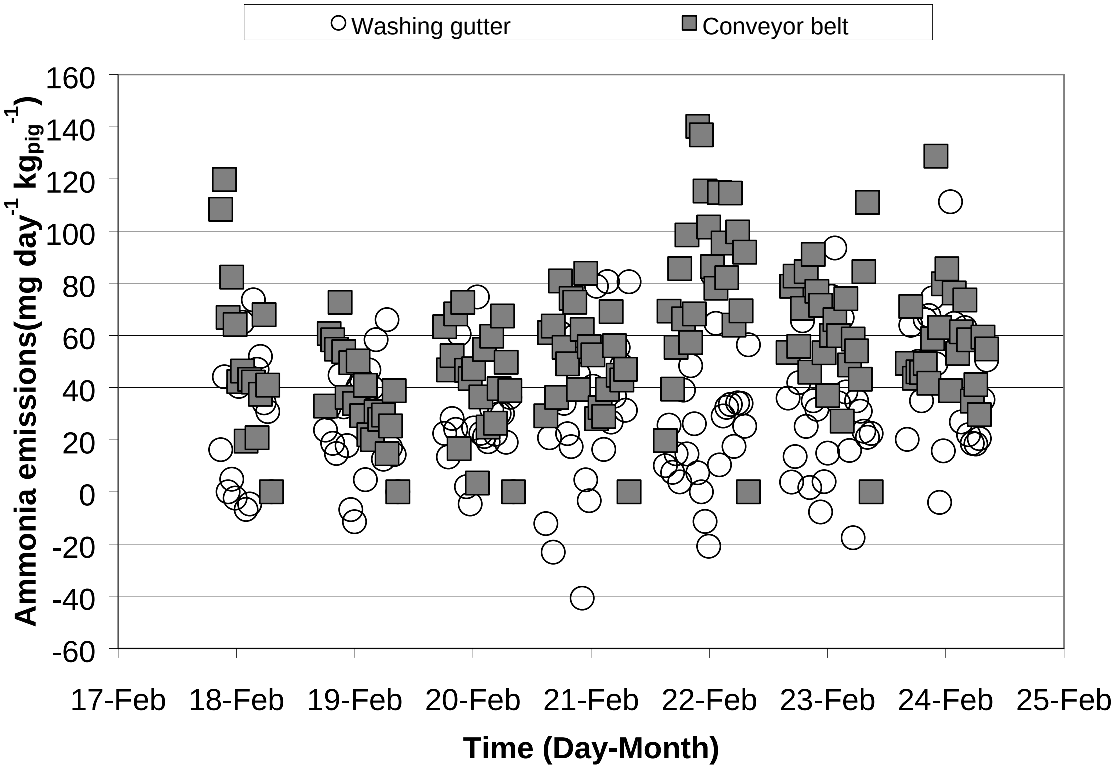

Figure 15 Ammonia emissions from experimental chambers February 17 - 25, 2004. This week had the lowest average weekly emissions of all the trials for the washing gutter chamber.

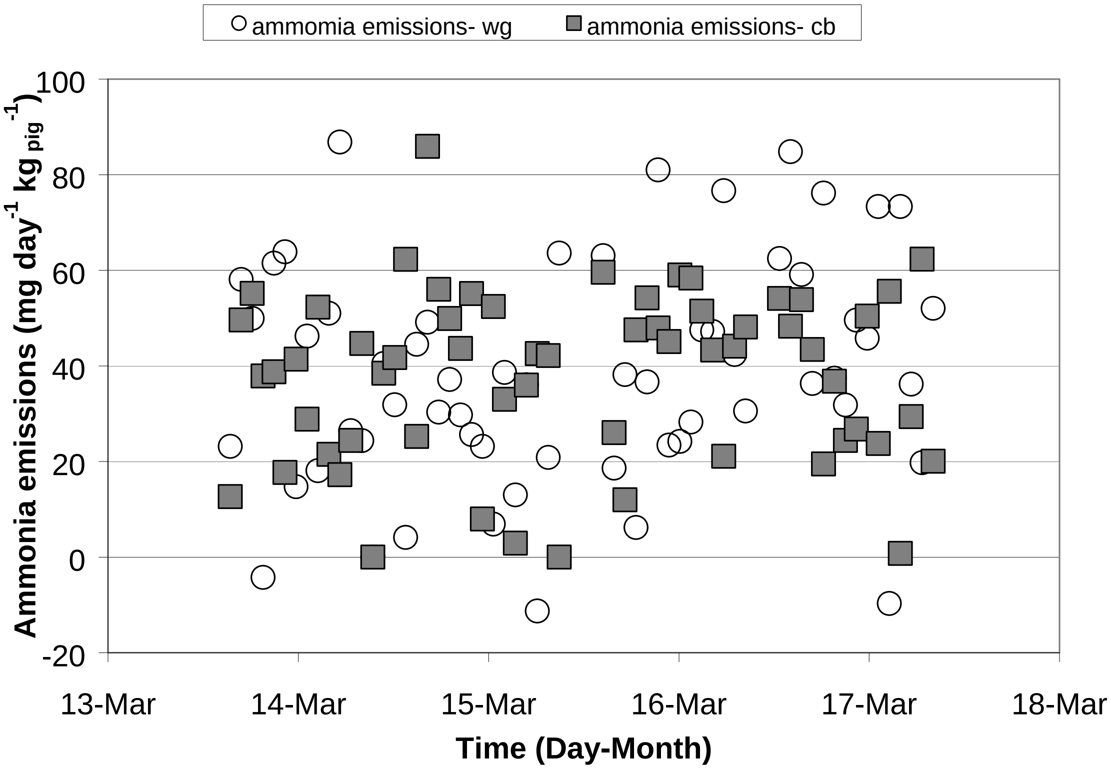

Figure 16 Ammonia emissions from experimental chambers from March 13 – 18, 2004. This week had the lowest average weekly emissions of all the trials for the conveyor belt system.

These average weekly emission values were used in the statistical analysis of the systems and the frequencies, and no significant differences were found between the systems and frequencies of operation. Based on the statistical analysis, both systems provided the same level of ammonia emissions and operating the cleaning systems more frequently did not reduce emissions (Fig.17).

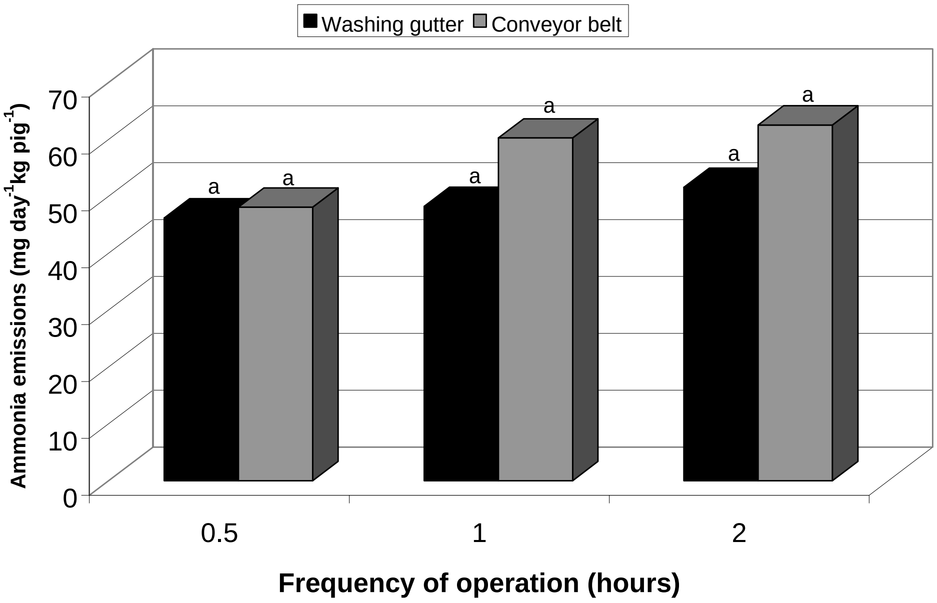

Figure 17 Average ammonia emissions from the experimental chambers over all the trials. Averages followed by the same letter are not statistically different (P>0.05).

4.4 Room Air Conditions

4.4.1 Temperatures

The temperature set points in the chambers varied a little depending on the average weights of the animals in the chambers, but the two chambers had the same set points at all times. Measured temperatures in the conveyor belt chamber were usually higher than in the washing gutter chamber (Fig.18), perhaps due to a controller calibration error at the beginning of the experiment.

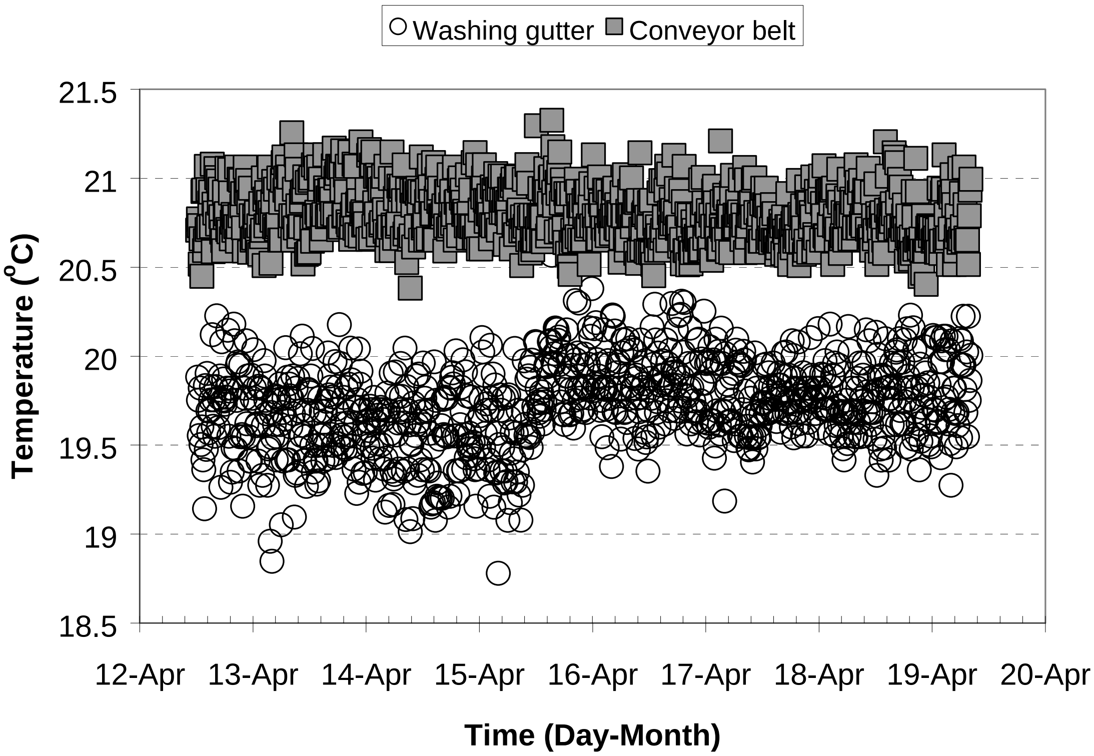

Figure 18 Temperatures in the experimental chambers from April 12 - 19, 2004.

Table 2 shows the actual average temperature, relative humidity and ventilation rate in each of the chambers for each of the trials. The conveyor belt chamber temperature averages are almost 1°C higher than the washing gutter chamber. Since ammonia volatilizes more quickly at higher temperatures (Muck and Steenhuis, 1981), this may have made ammonia emissions higher in the chamber with the conveyor belt than they would have been at a lower temperature. Controller calibration is a problem that will need correcting before any other trials are started in these chambers.

Table 2 Temperature, relative humidity and ventilation rate in the experimental chambers.

Date	Frequency (hours)	Temperature (°C)		Relative Humidity (%)		Ventilation Rate (L s^{-1} pig^{-1})	
		Washing gutter	Conveyor belt	Washing gutter	Conveyor belt	Washing gutter	Conveyor belt
Feb 17	2	19.7	20.8	54.9	37.0	11.2	10.4
Apr 12	2	19.7	20.8	44.9	38.8	11.4	11.0
Apr 20	2	20.0	20.9	45.7	37.0	16.5	17.0
Mar 3	1	19.8	20.9	46.6	35.0	11.4	10.8
Mar 20	1	19.9	20.8	47.2	38.4	12.4	11.4
May 8	1	18.6	19.3	47.5	42.0	18.9	16.1
Mar 13	0.5	19.9	20.8	64.4	39.9	12.2	11.2
Apr 2	0.5	19.7	20.8	60.7	43.6	13.5	11.0
May 19	0.5	18.0	18.9	60.3	55.3	20.2	9.0
Means		19.5	20.4	52.5	40.8	14.2	12.0

4.4.2 Relative humidity

The relative humidity increased in the washing gutter chamber each time the washing water was turned on (Fig. 19), and quickly returned to pre-wash values (although still higher values than in the conveyor belt chamber) when the ventilation rate increased. This cycling was not noticeable in the conveyor belt chamber, as the wash water was enclosed within the drain gutter, and was not in contact with as much of the chamber air.

Table 2 illustrates the difference between the two chambers when average relative humidity is compared. The washing gutter average relative humidity for each trial is at least 5% RH higher, and up to 24.5% RH higher than in the conveyor belt room. It is not known how this would affect the trials, but there is a possibility of some ammonia leaving the chamber with the wash water, as ammonia is easily dissolved in water. Scrubbing the contamination out of the air with water could affect future measurements of contamination from other sources as well as the measurement of contamination from manure.

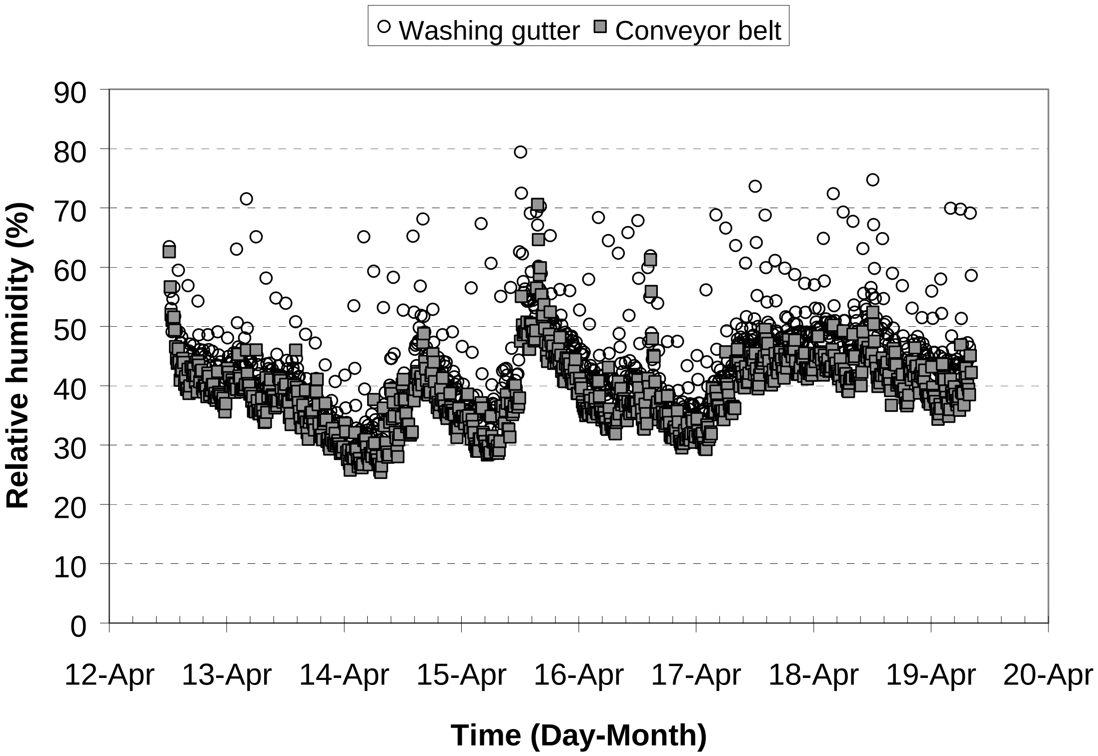

Figure 19 Relative humidity in the experimental chambers from April 12 - 19, 2004

4.5 Animals

Average weights and average daily gains for each group of animals on trial is shown in Table 3.

Table 3 Average pig weights and average daily gains

Date	Frequency (hour)	Average Weight (kg)		Average Daily Gain (kg day^{-1})	
		Washing Gutter	Conveyor Belt	Washing Gutter	Conveyor Belt
Feb 17	2	26.45	24.70	0.79	0.80
Apr 12	2	29.55	27.55	0.99	1.59
Apr 20	2	27.30	26.95	1.17	1.12
Mar 4	1	27.15	28.00	0.64	0.77
Mar 20	1	26.3	24.55	0.84	0.90
May 8	1	37.40	35.85	1.00	0.90
Mar 12	0.5	27.44	26.27	0.97	1.13
Apr 3	0.5	19.84	22.43	0.76	0.99
May 19	0.5	25.70	24.55	1.06	0.99
Averages		27.68	26.76	0.91	1.02

Recent research work done in the same barn, in similar sized pens, showed average daily gains (ADG) of 0.69 kg day^{-1} for similar weights of pigs (Payeur, 2003). In this experiment, only one room in one trial had a lower ADG than this benchmark. This indicates that the pigs in these trials did better than expected as far as weight gain is concerned, although these measurements were done simply to verify that the pigs were doing well in the rooms.

4.6 Water Usage

The manure handling system in the washing gutter chamber used approximately 58 L (58 kg) of water every time it cleaned the dunging area. No records were kept of water usage in the conveyor belt chamber or of drinking water in either chamber. However, the water disappearance in the same research facility was found to average 6.2 kg pig^{-1} day^{-1} using wet/dry feeders in a previous experiment (Christianson 2003). Thus, for the 10 pigs in the washing gutter chamber, the drinking water usage for an entire day is likely only slightly higher than the usage resulting from running the manure handling system once. Clearly, the system uses far too much fresh water to be commercially acceptable, but for research purposes on a limited scale, this was tolerated.

4.7 Dust Measurements

Dust measurements varied widely (Table 4), with total counts being between 4937 and 92392 particles m^{-3}. There are no clear trends between the two manure handling systems, or the different frequencies of cleaning.

Table 4 Particle counts for each trial

Date	Freq (hour)	Dust Particles >0.3 µm (per m^3)		Dust Particles >0.5 µm (per m^3)		Dust Particles >1.0 µm (per m^3)		Dust Particles >5.0 µm (per m^3)	
		Washing Gutter	Conv Belt	Washing Gutter	Conv Belt	Washing Gutter	Conv Belt	Washing Gutter	Conv Belt
Feb 19	2	21801	62661	7187	7772	5268	5759	2029	2317
Apr 15	2	18754	18258	10936	11068	9044	9205	3746	3511
Apr 23	2	29928	9011	21308	5064	17239	4360	6399	1902
Mar 8	1	4937	7864	2610	4549	2140	3771	914	1483
Mar 25	1	12727	19412	6359	10989	5001	8825	2210	3678
May 11	1	15563	25293	5343	14364	4246	11694	2016	5420
Mar 17	0.5	8572	19033	2686	10524	2088	8722	871	3977
Apr 5	0.5	51979	92392	17698	18614	6725	9547	520	3549
May 22	0.5	15204	85764	6733	21635	5402	8795	2383	2364

To put these measurements into perspective, particle counts were taken in another grow/finish room and in the hallway outside the rooms. These measurements are shown in Table 5.

Table 5 Particle counts compared to other places in the barn

Date	Freq (hour)	Dust Particles >0.3 µm (per m^3)		Dust Particles >0.5 µm (per m$^{3)}$		Dust Particles >1.0 µm (per m^3)		Dust Particles >5.0 µm (per m^3)	
		Washing Gutter	Conv Belt	Washing Gutter	Conv Belt	Washing Gutter	Conv Belt	Washing Gutter	Conv Belt
Feb 19	hall	89550		33035		21310		6701	
Feb 19	Rm 129W	104808		37529		21807		9667	
Ave	2	23494	29976	13143	7968	10517	6441	4058	2577
Ave	1	11076	17523	4771	9967	3796	8097	1713	3527
Ave	0.5	25252	65730	9039	16924	4738	9021	1258	3297

The cleanliness of the chambers (as noted by visual inspection each day) is reflected in the dust particle counts. The lower the total counts, the cleaner the chamber was noticed to be. However, because the dust comes from the feed and the animals themselves as well as the manure, the dust measurements may not be useful for more than comparisons between the two chambers. The dust particle counts in both the chambers are much less than that measured in the other room (129W), until the last 2 trials (when ventilation problems made cleanliness an issue). The hallway counts were almost as high as the room (129W) tested for comparison.

Increasing cleaning frequency did not always make the chambers cleaner or the dust particle count lower. The counts do not follow exactly the same trends as the ammonia emissions, where more frequent operation reduced emissions.

4.8 Discussion about System Efficiency

4.8.1 Ammonia Emissions

The systems tended to control the ammonia emissions better when cleaning was done more frequently, although no statistically significant difference was found when the emission levels were compared. There were a number of things that contributed to the difference in emission levels being less than expected. The pigs in the rooms quickly learned when the cleaning cycle was about to begin. As they anticipated the system running, they would move into the dunging area and most of the fouling happened in the few minutes just before and during cleaning. This eliminated much of the advantage of running the systems more frequently. Also, when the areas were cleaned more often, there was more water tracked up onto the solid flooring, which tended to encourage the pigs to urinate on these wet areas near the dunging area.

The ammonia emissions from the washing gutter chamber were always slightly lower than the conveyer belt chamber, although the difference was not statistically significant ($P>0.05$). In both chambers, dunging did occur in areas of the pens that did not get cleaned, and this may have produced ammonia in quantities that overwhelmed the difference between the two systems. The chambers were set up to be identical but there were obvious differences. The relative humidity in the washing gutter chamber was higher than in the conveyor belt chamber, and peaked every time the system was run. The conveyor belt chamber was warmer, which could reflect a controller calibration problem. This may have affected ammonia emissions levels, as ammonia volatilization occurs more rapidly at higher temperatures (Muck and Steenhuis, 1981). It would also affect the cleanliness of the chamber (which in turn affected ammonia emissions), since in these trials the pigs learned to use the dunging area quicker when the air temperature was cooler.

The background ammonia levels varied far more than the approximately 2-4 ppm of ammonia added by the manure from the pigs in the experimental rooms. So there was variation introduced related to the timing of the testing (as only one sampling site could be tested at a time). It was hoped that some of the variation introduced by the timing was removed by averaging the ammonia added to each chamber over the course of each week, but it would have been better to reduce the background ammonia levels directly. One partial solution to the problem would be to build chimneys above the inlets to the room area, so any air entering the system is drawn from the roof area instead of the eaves, as roof air would have mixed with more outside air and should contain less ammonia. Another solution would be to remove the background ammonia with an air scrubber system before allowing the air to enter the rooms.

The temperature and air inlets had a huge effect on the cleanliness of the rooms. Fouling in areas other than the dunging area usually could be solved with adjustments to the temperature and air inlet settings. Problems with the controllers in the ventilation systems affected the cleanliness as well as the ammonia emissions.

Occasionally the difference in static pressure across the pressure transducer was greater than the range the transducer was able to measure. This ventilation data was unusable, and the average ventilation rate was calculated over the appropriate time period without this data included.

4.8.2 Washing Gutter System

The water used for washing the dunging area in the washing gutter chamber was heated by the boiler in the barn, which usually meant the water was quite warm. Some of the groups of pigs liked to roll in the warm water when the system was running, which could affect measurements of the air contamination arising from the animals themselves when it is time to find the source of the individual contaminants. However, this would not be as large a concern as the fact that zero air contamination levels were not reached using this manure handling system. The pigs playing or rolling in the gutter while the water was running helped to clean the gutter, and remove any buildups that happened. Occasionally the boiler was not working (so cold water was used for washing), which meant the pigs were not as motivated to be in the gutter when the water was running, and this affected the cleanliness as well as the amount of water that escaped from the dunging area (as noted in visual inspections).

Some problems were encountered in positioning the nozzles in the washing gutter in order to reduce the amount of water that hit the pen wall. This would have been easier if the steel plate holding the nozzles was wider, which would make the gap between the solid pen flooring and the dunging area wider as well. This gap was deliberately left quite narrow to restrict the pigs' access to the nozzles, but the gap could be wider if the nozzles were also moved further under the solid flooring, and still not allow any of the pigs to reach the nozzles with their snouts. Imperfections in the slope of the dunging area also made it difficult to position the nozzles so the water did not bounce off the floor or the pen wall.

Because of the problems with adjusting the nozzles, some spray from the washing gutter system hit the pen wall and was reflected into areas other than the dunging gutter. Flashing was installed at the top of the pen wall to limit the amount of water reflected out of the dunging area, but some water still escaped. This produced wet spots just outside the dunging area on the sloped solid flooring, which encouraged the pigs to use these areas as an extension of the dunging area, and any manure in these areas was not cleaned when the system ran. This was more noticeable as the system was operated more frequently.

There were some leaks in the system, and water tended to accumulate on the floor. Most of the leaks were at the intersection of the metal holding the nozzles with the dunging area concrete, and caulking was added to this area. The concrete was not sloped perfectly, and some of the liquid ran to the side of the dunging area without the gutter.

A Datalogger controlled the washing gutter system. The twelve nozzles were configured to run in two banks of six. The pressure was then just enough to remove all the manure from the dunging area. The volume of water available for washing would occasionally be reduced if there was hot water being used in other places in the barn, but the system would run with partial volume and return to full volume as soon as there was water available.

The biggest disadvantage of the washing gutter system is the amount of water needed for a cleaning. The amount of fresh water used in one cleaning is almost as much as the 10 pigs needed for drinking all day.

4.8.3 Conveyor Belt System

The conveyor belt worked well without any flooring above it. The belting chosen had a raised design to eliminate slipping, and no pigs were observed sliding on the belt. Perhaps an untextured belt with more incline to allow even better drainage would also work. This may be the first time this was tried with pigs, and their reactions are interesting. They did not avoid the belt, and did not seem to mind their dunging area moving them into a wall occasionally. They were very curious about the belt disappearing under the wall, and usually there would be pigs watching the belting vanish, although none of the pigs ever seemed to be curious about the belt appearing on the other side of the dunging area. Generally, in both rooms, the manure handling system starting up seemed to encourage the pigs to move into the dunging area, or race around the pen in play.

The conveyor belt system was controlled by a datalogger, which also controlled the washing water for the belt, so these were easily synchronized. There were no problems encountered with the belt operation, other than the controller not tolerating pressure washing well. A waterproof electrical box was installed to house the controller so that pressure washing the room was not a problem.

There was always some water on the floor in the chamber, some from the high-pressure line leaking, and some from the collection of the washing water. Two rubber seals were installed in the gutter to help with the leaks of the washing water, but the raised surfacing of the belt did not allow the rubber to seal tightly.

The motor for the conveyor belt was quite close to the chamber floor, and flooding was a concern (Fig.6). A float and switch were installed to create a short circuit in one of the electrical lines carrying current from the datalogger if the level of the water on the floor of the chamber was almost high enough to get the motor wet. This would allow the valve to close, and the belt to run, but the valve would not reopen until the level of water in the chamber had dropped.

The high-pressure water came from the same pump that supplied the pressure washing lines in the rest of the barn, and there was not enough water volume to run both the washing of the belt and a pressure washing wand at the same time. This meant that any person pressure washing in the barn had to watch the time and turn off their water supply before the conveyor belt system was due to run. Failure to turn off their water in time meant that the belt washing did not occur, and a mercury switch in the maintenance room had to be manually reset to allow the shared pump to start again. Often, this affected the cleanliness of the experimental room. A pressurized tank large enough to hold water for one wash would eliminate this problem, as would having a tank and a pump for that system alone.

There was a gap below one pen wall to allow solid wastes to be conveyed out of the pen, and this caused some concern about pigs getting caught in the gap. An electric eye was installed that would turn the belt movement off if the pen wall above the gap was pushed, but it is not known if this ever was activated by the pigs, as it was automatically reset. Certainly, no pigs were ever found trapped in the gap.

The belting did not appear to wear or get mistreated by the pigs. They had no access to the sides of the belt, or to any of the working parts of the conveyor. The metal parts on the conveyor belt were beginning to rust, and manure was difficult to wash out of some areas of the conveyor. It probably smelled like manure, but it worked well.

4.8.4 Zero Contamination

The two manure handling systems did not totally eliminate the air contamination associated with the excreta, so another method of manure handling will have to be used in the studies to determine the source of the individual contaminants. Some fouling happened outside the dunging area, and there was some tracking of manure into the other parts of the pen, and this likely contributed to the air contamination measured in the room. Comparing the ammonia emissions, no significant difference ($P>0.05$) was found between the two manure handling systems tested, or the three frequencies tested.

Excreta collection bags could be used as an alternative method of eliminating the air contamination. These bags have been used in other experiments in the research facility. Velcro circles are usually glued to the hind end of pigs to hold plastic collection bags in place, and ideally should eliminate any contact of the air with the manure. On a practical note, the bags need to be changed often enough to be sure that their weight does not dislodge the Velcro fastening or the glue, which happens much more quickly as the pigs grow and the amount of manure they produce increases. Collecting both urine and feces in this manner would also increase the risk of mishaps with the bags; they are primarily used for only feces collection. The pigs cannot have physical contact with another pig's excreta bag, so the pigs would need to be penned separately in the room.

5 SUMMARY

5.1 Conclusions

One of the original objectives of this experiment was to develop a manure handling system that produced close to zero levels of air contamination in the experimental chamber. Ammonia emissions were used as a measure of the efficiency of the systems. The two designs tested (a washing gutter and a conveyor belt) produced emissions averaging 48.7 mg day^{-1} kg_{pig}^{-1} and 57.0 mg day^{-1} kg_{pig}^{-1}, respectively. While these emissions were less than similar rooms in the same facility (47% and 38% lower), another method will have to be found to achieve zero emissions when the sources of individual components of the contamination are to be examined.

Another objective of this experiment was to produce a range of levels of air contamination in the chambers. Health and productivity testing with a range of air qualities could be achieved with either of the two manure handling systems tested here, as no significant difference was found in ammonia emission levels from the two chambers.

5.2 Recommendations

In order to achieve close to zero air contamination levels from manure in the chambers, another method will have to be developed. One possible solution is to use excreta collection bags. Working properly, these bags would eliminate contact of the manure with the air, and thus control the contamination. The pigs would then have to be housed individually (so they did not destroy each other's bags), and the total air contamination could be affected by the lack of direct contact between pigs. However, collection bags may still be the best option to allow accurate collection of measurements of the air contamination due to other sources of contamination.

In these trials, the pigs were introduced into clean chambers and given a few days to become accustomed to the manure handling system. The pigs were then taken out of the chambers while they were thoroughly washed, and reintroduced into the clean dry chambers to allow testing to take place. This system worked well, and is recommended when intermediate levels of contamination are needed. The levels of contamination were not significantly different in these trials, so it is recommended that longer periods of time between cleanings be used to see of the levels of contamination can be adjusted to a greater extent this way.

Training the pigs in the washing gutter chamber was quicker than training in the conveyor belt chamber, and the system was simpler and easier to run, so the washing gutter system is recommended for the health and productivity testing phase of the project.

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7 APPENDICES

7.1 Data Analysis – SAS Program and Results

```
CARDS;
RUN;
PROC SORT;
BY freq room;
PROC GLM;
CLASS freq room trial;
model emissions= freq trial(freq) room room*freq;
LSMEANS Freq/STDERR PDIFF E=trial(freq);
TEST H=freq E=trial(freq);
RUN;
```

freq	trial	room	emissions
2	1	wg	0.0302
2	2	wg	0.0639
2	3	wg	0.0608
1	1	wg	0.0462
1	2	wg	0.0442
1	3	wg	0.0543
0.5	1	wg	0.0396
0.5	2	wg	0.0545
0.5	3	wg	0.0445
2	1	belt	0.0587
2	2	belt	0.0741
2	3	belt	0.0511
1	1	belt	0.0730
1	2	belt	0.0572
1	3	belt	0.0507
0.5	1	belt	0.0388
0.5	2	belt	0.0457
0.5	3	belt	0.0598

```
                                The SAS System                            1
                                          09:03 Thursday, June 24, 2004

                              The GLM Procedure

                           Class Level Information

                       Class          Levels    Values

                       Freq                3    0.5 1 2

                       Room                2    belt wg

                       Trial               3    1 2 3


                         Number of observations    18
```

```
                              The SAS System                                2
                                               09:03 Thursday, June 24, 2004

                             The GLM Procedure

Dependent Variable: Emissions

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

Model                       11       0.00170444     0.00015495      1.23   0.4175

Error                        6       0.00075423     0.00012570

Corrected Total             17       0.00245866


            R-Square     Coeff Var      Root MSE    Emissions Mean

            0.693237      21.21884      0.011212          0.052839


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

Freq                         2      0.00031535     0.00015768      1.25   0.3506
Trial(Freq)                  6      0.00098595     0.00016433      1.31   0.3766
Room                         1      0.00031001     0.00031001      2.47   0.1674
Freq*Room                    2      0.00009312     0.00004656      0.37   0.7052


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

Freq                         2      0.00031535     0.00015768      1.25   0.3506
Trial(Freq)                  6      0.00098595     0.00016433      1.31   0.3766
Room                         1      0.00031001     0.00031001      2.47   0.1674
Freq*Room                    2      0.00009312     0.00004656      0.37   0.7052
```

7.2 Checking calibration on sampling setup

The gas analysing system was tested on July 30, 2004. Zero and span gases were introduced to the manifold, and the resulting ammonia concentrations recorded. Then zero and span gas were put into a bag and this bag put onto the sampling tube in one of the chambers. A small leak was discovered in one of the connections, so this was repeated. A graph of the resulting ammonia concentrations was made (Fig. 18).

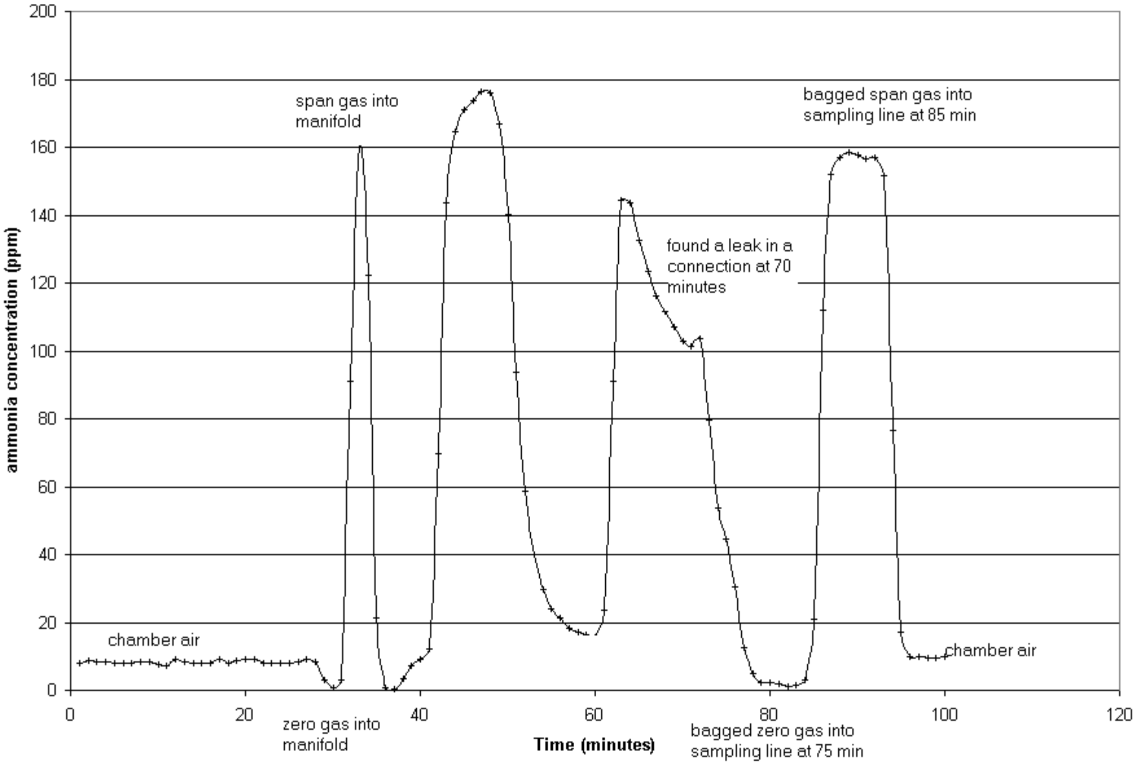

Figure 20 Ammonia concentrations while testing sampling system.

7.3 Drawings of the experimental facilities

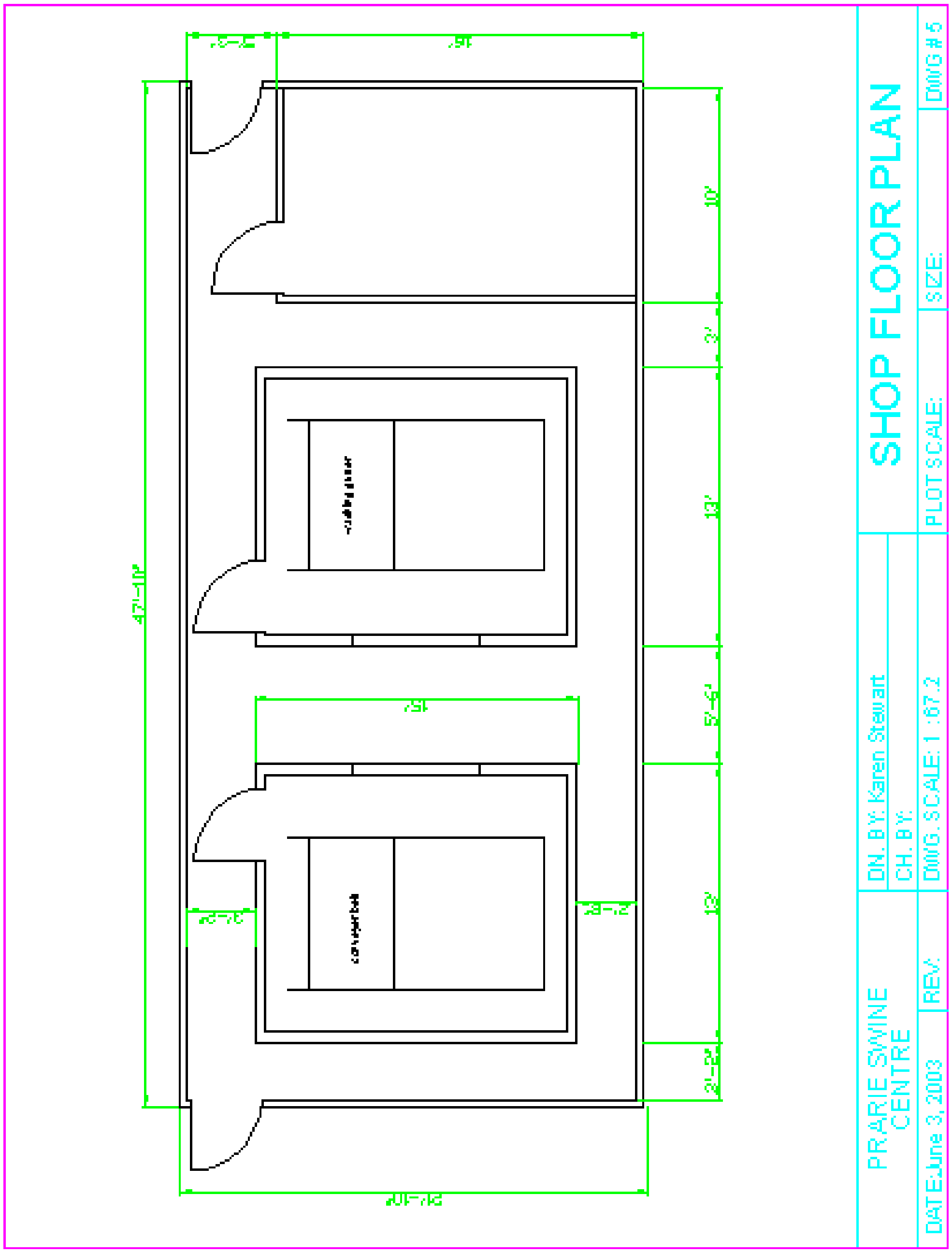

Figure 21 Floor plan of experimental facilities showing the experimental manure handling systems.

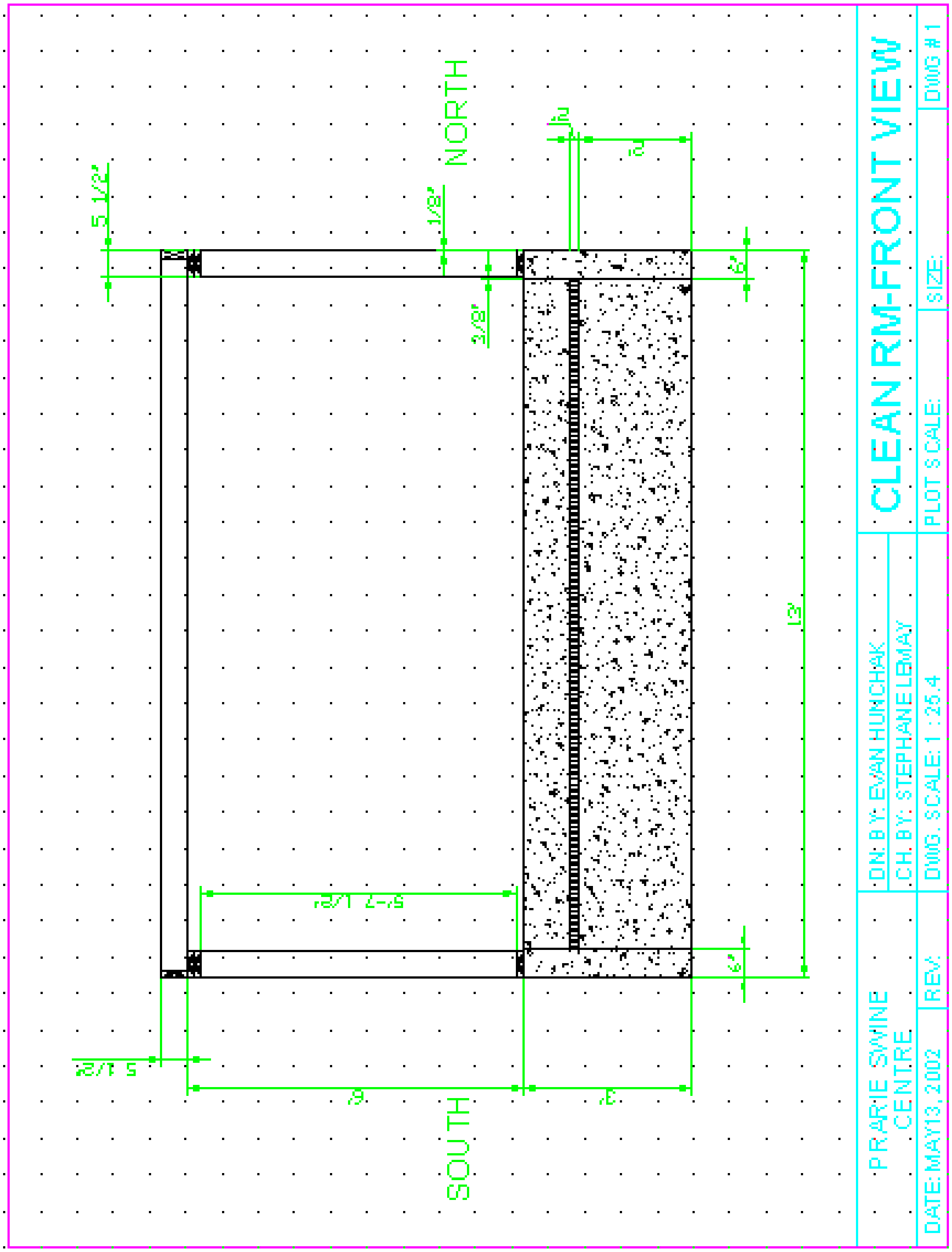

Figure 22 Cross sectional view of experimental chamber.

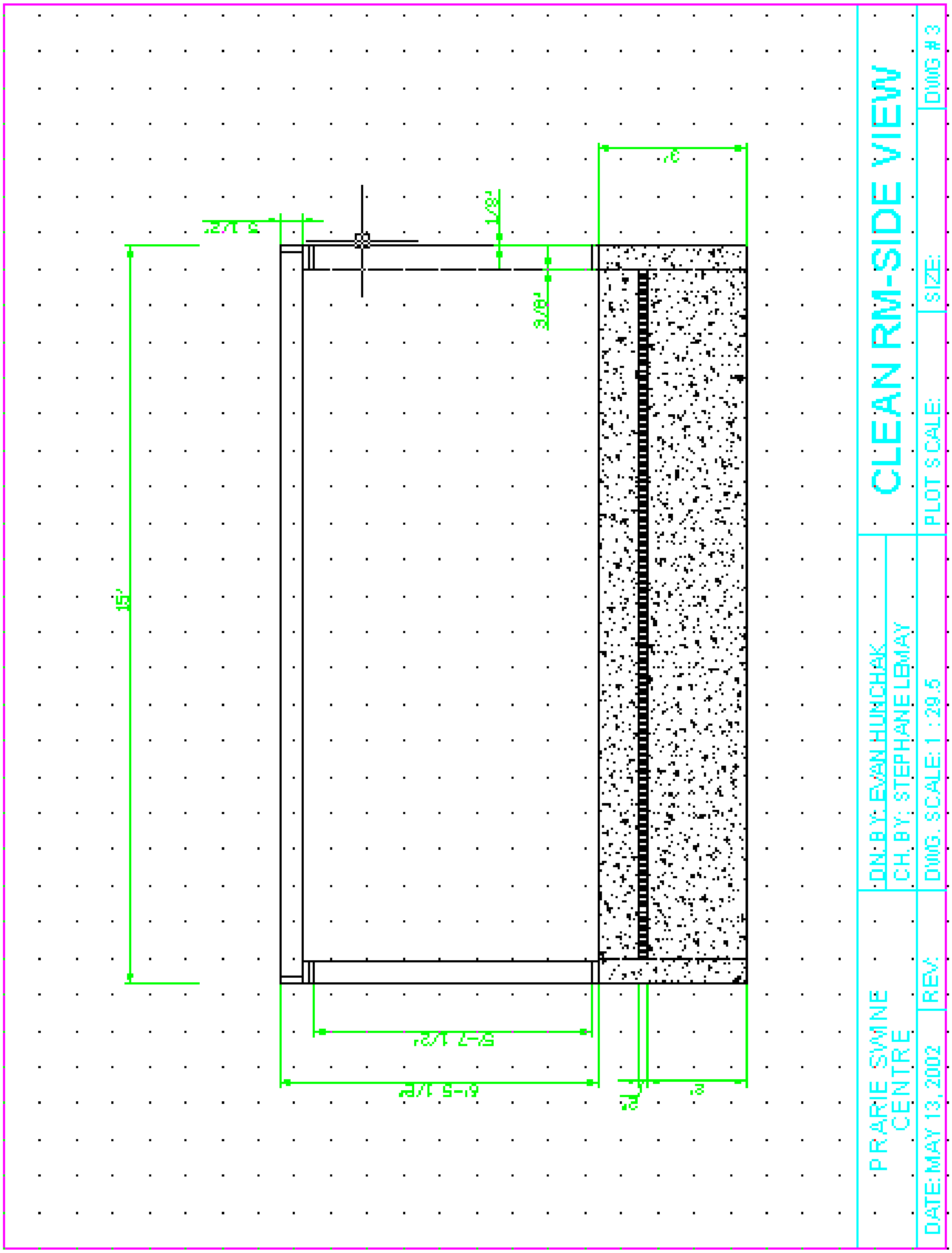

Figure 23 **Cross sectional view of experimental chamber.**

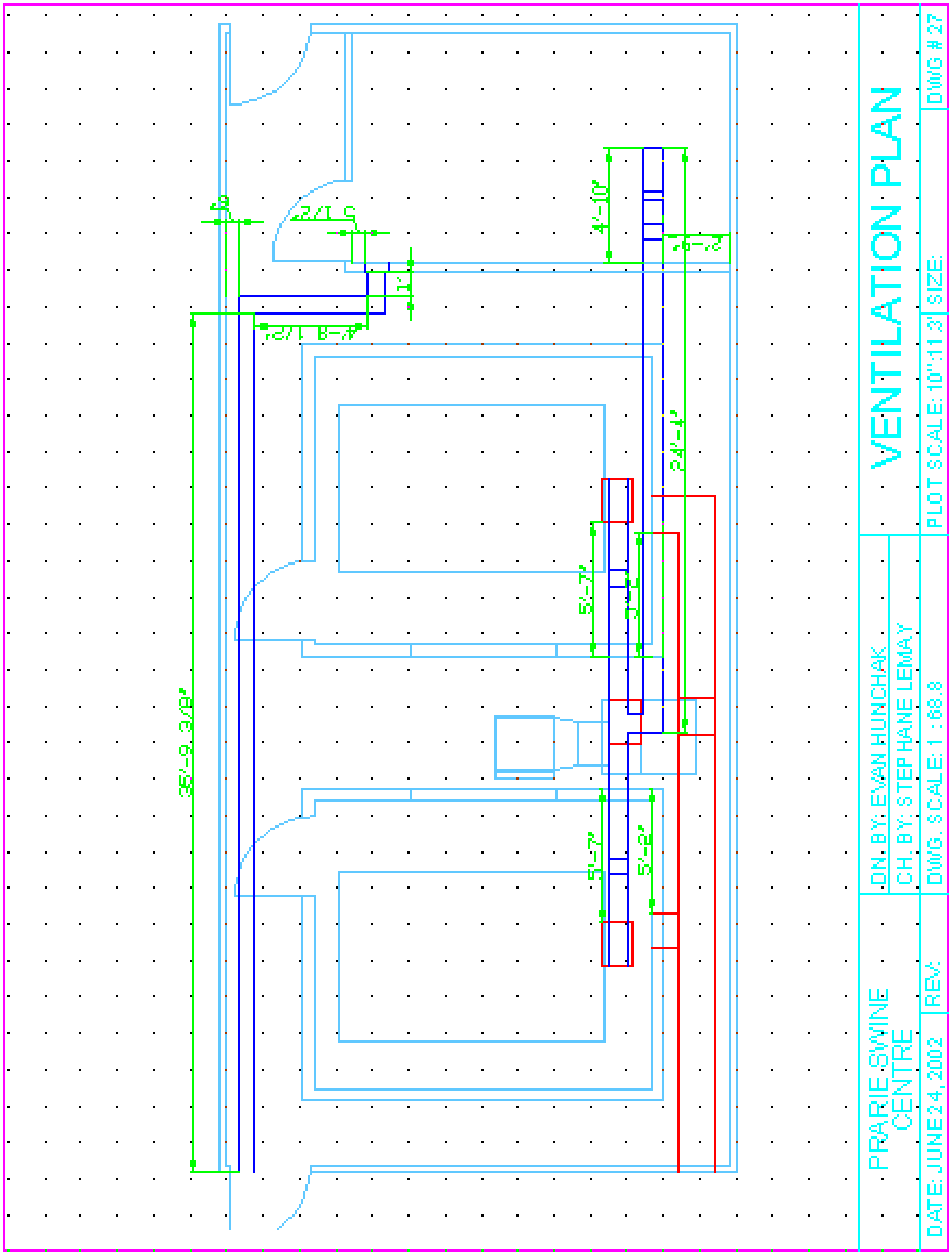

Figure 24 Ventilation plan for the experimental facilities.