MEASUREMENT OF AIR POLLUTANT EMISSIONS FROM A CONFINED POULTRY FACILITY.

by

Olumuyiwa O. Ogunlaja

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Approved:

Dr. Randal S. Martin Major Professor	Dr. David K. Stevens Committee Member

Dr. Rhonda L. Miller
Committee Member

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INTRODUCTION

Air pollutants from poultry houses may represent a significant source of pollution to the wider environment. Reasonable estimates of pollutants emission rate (ER) from poultry facilities are needed to guide discussion about the industry's impact on local and regional air quality. Quantitative estimates are also required of the effectiveness of the various major abatement strategies for reducing major pollutants like ammonia emission from facilities to provide guidance to the industry on the most effective strategies for managing aerial pollutant emission. Therefore, information regarding the concentration and emissions of gases and dust from poultry facilities is highly needed. Aerial pollutants of particular interest include particulate matter (PM) and gaseous species, such as ammonia (NH_3), hydrogen sulfide (H_2S) and Volatile Organic Carbon (VOC's). Concentrations of dust and these gases usually have negative impact on both human and animal health. Dust particles carry odor, gases, and bacteria and therefore are of the greatest health concerns. In poultry buildings, the combination of dust and other air contaminants such as ammonia may cause respiratory disease, increased mortality rates, and reduced bird growth (Maghirang et al. 1991). Control of PM emissions from poultry facilities is thought to improve health of workers, birds, and neighbors. The indoor air concentration of dust, hydrogen sulfide and ammonia are regulated through the Occupational Health and Safety Administration (www.OSHA.gov).

According to the EPA's new air quality consent agreement with animal feeding operations, all the animal operations need to comply with the federal air quality laws (EPA, 2005). Among animal production facilities, poultry facilities create the most concern with regard to emitting the amounts of PM and ammonia that could potentially violate the Clean Air Act (Heber, 2004). Therefore, dust and ammonia emissions have created a major challenge for viability and growth of the egg-laying industry.

The ambient air quality is a function of the amount of dust and gases emitted from the facilities and the downwind transport and transformation of these constituents. However, there is insufficient data available to reliably estimate how much air pollution is emitted by poultry facilities, and how much emissions may be influenced by climate, animal species, and design and management of the facility.

The mass of Ammonia and Dust emitted from a facility is the product of source concentration of the gas and air exchange rate through the source while employing adequate unit conversion and corrections for temperature and barometric pressure effects. It is quite challenging to reliably quantify pollutants concentration and air flow in CAFOs on a continuous and prolonged basis. There are so many obstacles like the harsh nature of the sample air, high pollutant concentrations beyond operational limits of many analytical instruments. The determination of the ventilation rate through the poultry barn using manual FANS method is also pretty difficult due to the large number of fans involved, inherent variations among them (belt tightness, dust on blades, degree of shutter opening, e.t.c) for mechanically ventilated facilities, and deviation of fan working condition from those under which the fan performance curves were developed.

Currently, federal regulation of agricultural air pollutant emissions is limited. The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act (EPCRA) require any facility to report when the 45.5 kg/d production threshold of hazardous material is exceeded; hazardous waste includes ammonia and hydrogen sulfide, which are commonly emitted from agricultural facilities (NRC, 2003). The Clean Air Act (CAA) limits emissions of volatile organic compounds (VOC) and PM in certain industries (not including agriculture). The CAA also regulates ambient PM concentrations under the National Ambient Air Quality Standards (NAAQS), but there are no regulations which specifically address agricultural PM emissions.

Objectives

The purpose of this study is to provide quality and reliable air emission data from representative laying farms in the U.S., in an effort to determine whether the farm might fall under regulatory authority. This study will collect data employing sound scientific principles, which will serve as the beginning of a database to which new data can be added as emissions and against which control technologies can be compared. Specific objectives of this work were to:

1. Determine whether individual egg laying farms are likely to emit particulate matter (Total suspended particulate (TSP), particle with aerodynamic diameter less than 10 and 2.5 microns (PM10 and PM2.5), and volatile organic compounds (VOC) in excess of applicable Clean Air Act (CAA) thresholds. Applicable federal emission thresholds for attainment areas are 250 tons per year for TSP and 100 tons per year for PM10, PM2.5, and VOC. Although some States Clean Air Act threshold vary.
2. To investigate the possible difference in pollutant concentrations between the two poultry management practices – High rise or ventilated deep pit house and manure belt or ventilated belt .

3. To carry out a manure Composition Analysis for pH, Total Solids, volatile solids, Total Kjeldahl Nitrogen (TKN) and Total Ammoniacal Nitrogen (TAN).
4. Determine whether individual egg laying farms are likely to emit ammonia (NH_3) and hydrogen sulfide (H_2S) in excess of applicable Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) reporting requirements. The applicable reporting requirement is 45.5kg/day for both ammonia and hydrogen sulfide.

Literature Review

Air emission sources from poultry production sites include buildings, feedlot surfaces, manure storage and treatment units, dead poultry compost structures, and a variety of other smaller emissions sources. Each of these sources will have a different emission profile (i.e., different odor, gases, dusts, and microorganisms emitted) with rates that fluctuate throughout the day and throughout the year. Therefore, quantifying airborne emissions and their impact on the surrounding environment is extremely difficult. Although there are two major sources of agricultural air emissions: animal housing and waste management systems, this section will provide information on emission measurement and published data on gas, and particulate emissions from poultry housing. The research findings reported in this section are organized by specific compound (ammonia, nitrous oxide, hydrogen sulfide, and dust). Published emission values from poultry housing were reported for each compound.

Emission Measurement

Emission refers to the rate at which gases or particulates are being released into ambient air. It is also a mass flux per unit area and time from a particular surface. This is in contrast to concentration-only measurements. Emission rates are determined by multiplying the concentration of a component by the volumetric flow rate at which a component at a given concentration is being emitted. Surprisingly, while accurately measuring gas and odor concentrations within facilities is feasible, the determination of building or manure management system emissions is not straightforward. For example, it is not sufficient to count the number of fans, multiply by some average fan ventilation rate, and then multiply by the gas concentration. Likewise, it is not sufficient to estimate mass flux of a specific gas from the surface of litter on a floor, or manure within the facility, and then assume the building emission is constant regardless of the number of fans running; nor would it be appropriate to assume all similar facilities exhibit similar emissions. While these aforementioned, crude estimates might be suitable for a rough imprecise estimate of building emission, at best they would be only useful for that point in time and they completely neglect the effect of daily husbandry activities (feeding, lights, etc) and disturbances to the thermal control systems (especially weather systems).

Gas emission rates are often normalized to the number and weight of animals by dividing the total emission rate by the number of animal units (AU), where one AU is equal to 500 kg of animal live weight. Emission expressed in terms of AU is often referred to as the emission factor. Area-specific emission, or flux rate, is determined by dividing the total emission rate by the emitting surface area. Thus the comparison of emissions from various studies is often difficult if not done on the same basis, such as AU, animal live weight, animal place, area, or volume or weight of manure. Furthermore, the definitions of AU and animal place are not standardized. Therefore, conversion of emissions reported in one study to the units used in another study is not always possible; and when done, may lead to misleading interpretations. Also, data collection periods vary widely, ranging from a few hours to several days. In some cases units from original data sources were converted to grams of compound per AU and per day for comparison purposes, but this may not fully correspond to actual emission measurements. Conversion of daily to annual emission values is not encouraged as emission rates vary widely during the year depending on season, air temperature, humidity, etc.

Ventilation Rates

Fans are the key components of mechanically ventilated systems in confined animal housing facilities for poultry in the U.S. Fans are used to create both air flow and air exchange. The fresh air conveyed by the fan supplies oxygen to the animal and removes heat, moisture and gaseous contaminants from the facility. The amount of air exchange required depends on animal size, number, type and climate. Fans are usually selected by a designer based on the static pressure difference between the inside and outside of the house. Fans in livestock and poultry houses usually operate at static pressures between 10 and 25 Pa (MWPS, 1990). Good environmental control inside the poultry house relies on the capacity of the fans to supply the required volume of air at the static pressure differential chosen for the house and conditions. The static pressure differential set-point is often varied during the year to create air flow patterns within the house to suit the growth stage of the animals and to suit the weather conditions.

When installed in an animal house, the fans are often fitted with one or more accessories, varying from screens, shutters or louvers and discharge cones. These accessories usually reduce the airflow and efficiency of a fan. However, the accessories are neccesary for proper functioning of the ventilation systems (Ford et al, 1999).

Figure 1. Fan installed on a poultry barn showing the discharge cones, louvers and protective metal nets.

A major impediment to determining emissions is the difficulty in knowing how much air is being exchanged. Mechanically ventilated facilities typically use a large number of fans and if the interior airspace is not well-mixed then gas concentration and hence emission rate may differ at each fan. Accurate measurement of airflow is difficult, and a number of factors commonly found in poultry and livestock facilities make this especially so, including dust accumulation on shutters and blades, loose belts, loss of building static pressure which results in variable ventilation effectiveness, and poor mixing, etc.

Simmons et al. (1998b) found that air flow through a 1220mm diameter fan was reduced by 2% when it was positioned within 300mm of another fan. Person et al. (1979) measured reduction of 23% to 39% in air flow due to the presence of louvers while Ford et al. (1999) showed that accumulated dirt on the shutter can reduce air flow by up to 40%.

Basically, three methods can be used for determining building ventilation rates. One method, used for in situ ventilation measurement, has been developed by Simmons et al. (1998a) and has been used in poultry facilities (Simmons et al., 1998b). The device is a motorized anemometer array controlled and monitored with a computer. It uses five propeller-driven DC generators mounted on a horizontal bar or rack. The bar travels vertically and the instruments perform an equal area traverse. Volumetric flow determinations can be made in either vertical direction (i.e. going up or down). Following the traverse, the total fan output is calculated as a function of the area of the opening of the anemometer array. Its accuracy has been shown to be within 1% when used with 122 cm diameter fans.

The second method uses heat production data and its relation to animal carbon dioxide (CO_2) production (Van Ouwerkerk and Pedersen, 1994, Phillips et al., 1998). This latter quantity is measured and the building ventilation rate is obtained by inverse solution of a building CO_2 balance. In addition to these two techniques, measurement of the building's static pressure may be used if fan manufacturer's performance data are available and if the fans are in a condition similar to the standard test fans used in the performance tests.

European studies on gas emissions from livestock and poultry facilities (e.g., Groot Koerkamp et al., 1998a), often estimate building ventilation rates derived from the relationship between metabolic heat production and the CO_2 production of the animals and manure (if stored in a deep pit, underneath the animals). The validity of this method is based on two factors: a) valid heat production values for the animals, and b) CO_2 production is solely from respiration of the animals. The use of certain literature heat production data, mostly dating back 20 to 50 years, has been questioned because of the drastic advancement in animal genetics and nutrition. Moreover, depending upon the manure handling systems, the measured CO_2 production can contain considerable contribution by microbial activities of the manure (e.g., manure storage in a high-rise building or deep-pit system). Therefore, building ventilation rates derived with the latest heat production data from intensive laboratory measurements should be more reflective of the modern genetics, nutrition, and manure management practices (Xin et al., 2001). Although this technique is less accurate than ventilation flow rate measurement, it has the advantage of being applicable in principle to both mechanically and naturally ventilated buildings (Phillips et al., 1998).

Ammonia

Ammonia is colorless, lighter than air, highly water-soluble, and has a sharp, pungent odor with detection threshold between 5 and 18 ppm. Gaseous NH_3 has a mean life of about 14 – 36 hours depending on weather. NH_3 is classified as a particulate precursor, i.e. in the vapor phase it will react with other compounds to form particulates. NH_3 and chemical combinations (NH_x) are important components responsible for acidification in addition to sulfur compounds (SO_x), nitrogen oxides, and volatile organic components (Finlayson-Pitts et al., 2000).

Aerial ammonia (NH_3) is the predominant pollutant gas in poultry production operations. Its generation is a result of microbial decomposition of uric acid in bird droppings. The EPA's emission inventory indicates that livestock management and fertilizer application contributed about 85% of total ammonia emissions in the U.S. in 1998, while publicly owned treatment works, mobile sources and combustion sources contributed about 15% of the total (U.S. EPA, 2002). Ammonia emission is environmentally important because of its contribution to the acidification of soils and increased nitrogen deposition in ecosystems.

The majority of NH_3 emissions from animals originate from a mixture of feces and urine and in poultry birds, the feces and urine combine to form the droppings. Nitrogen excreted in feces and urine is dominated by urea, uric acid, and undigested protein; the simplified degradation processes for each compound are shown in Equations 1 through 3 (Groot Koerkamp et al., 1998; Arogo et al., 2006). Urea ($CO(NH_2)_2$) is hydrolyzed by the enzyme *Urease* as shown in Equation 1 and is influenced by urease activity, pH, and temperature (Elzing and Monteny, 1997). Uric acid ($C_5H_4O_3N_4$) and undigested protein are degraded through microbial activity, shown in Equations 2 and 3, and are affected by temperature, pH, and moisture content (Whitehead and Raistrick, 1993). The urea-related reaction (Equation 1) is the most abundant of the three and contributes the most to NH_3 emissions (Arogo et al., 2006).

$$CO(NH_2)_2 + H_2O \xrightarrow{\textit{Urease}} CO_2 + 2\,NH_3 \tag{1}$$

$$C_5H_4O_3N_4 + 1.5\,O_2 + 4\,H_2O \xrightarrow{\text{Microbes}} 5\,CO_2 + 4\,NH_3 \tag{2}$$

$$\text{Undigested protein} \xrightarrow{\text{Microbes}} NH_3 \tag{3}$$

Ammonia is released through volatilization during waste storage, transport, and disposal. Ammonia volatilization from manure is influenced by many factors, including, but not limited to, total aqueous ammoniacal nitrogen (TAN) concentration, pH, wind speed, surface area, chemical and microbiological activities, surface cover, type of treatment, and air and water temperature (Arogo et al., 2006). For storage facilities located indoors, additional factors affecting volatilization and emission rates may include indoor and outdoor temperature, building ventilation rates, and waste dilution (Heber et al., 2000). Ambient NH_3 concentration is influenced by many factors, some of which are source strength, time/distance from release point, reaction rates with various compounds potentially present, mixing or planetary boundary layer height, and deposition rates (NRC, 2003).

Ammonia in housing facilities can also adversely affect bird performance and welfare. Moreover, ammonia is a source of secondary particulate matter $PM_{2.5}$ which is regulated under the US National Ambient Air Quality Standard (Baek and Aneja, 2004). The potential for additional federal air quality regulation accelerates the need for accurate estimates and mitigation of ammonia emissions. Various attempts have been made to quantify NH_3 emission from livestock production facilities (Burns et al. 2003; Groot Koerkamp et al. 1998; Hinz and Linke, 1998; Patni and Jackson 1996; Wathes et al., 1997; Maghirang and Manbeck, 1993). However, currently there are limited data in ammonia emission rates from U.S. commercial layer houses.

A recent ammonia emission inventory from UK agriculture estimated emission as 197 kt NH_3-N $year^{-1}$ (Misselbrook et al., 2000, Pain et al., 1998). Emissions from poultry housing accounted for 12% of this value. Table 1 lists published ammonia emissions from poultry housing.

Table 1. Ammonia emission factors from poultry housing

Production unit	**Notes**	**Emission Factor g NH_3 AU^{-1} day^{-1}**	**Reference**
Layer	Winter	190	Wathes et al. (1997)
Layer	Summer	300	Wathes et al. (1997)
Layer	Deep litter	177-261	Groot Koerkamp et al. (1998a)
Layer	Battery	14-224	Groot Koerkamp et al. (1998a)
Broiler	Winter and Summer	216	Wathes et al. (1997)
Broiler	Litter	53-200	Groot Koerkamp et al. (1998a)

Broiler	Litter	45	Demmers et al. (1999)
Broiler	Litter	5.8-8.4	Zhu et al. (2000a)

These measurements from poultry facilities indicate that ammonia emission factors vary 50-fold, from 0.24 to 12.5 g NH_3 AU^{-1} hr^{-1}. Emission factors from layer facilities seem to be consistently higher than those from broiler facilities.

Even though ammonia emissions from various European production facilities have been quantified (Groot Koerkamp et al., 1998; Hinz and Linke, 1998; Wathes et al., 1997), it may not be readily applicable to US counterparts, due to the differences in housing facilities, manure management practices, climate, etc. Currently in the United States, two major types of laying hen houses are in use, i.e. high-rise houses and manure-belt houses. For high-rise houses, solid manure is stored in the lower level of the building for about a year before removal. For manure-belt houses, manure is collected on the belt and removed from the house 2 to 7 times a week.

In a study examining gas and particle emissions from poultry, swine, beef, and dairy buildings in four northern European countries, Groot Koerkamp et al. (1998) reported the ammonia emission rates found in Table 7. Four facilities per housing type in each country were sampled for a 24-hour period under both summer and winter conditions. Concentrations were measured using a chemiluminescence analyzer at seven sampling points inside each house and one outside. The measured NH_3 concentrations and ventilation rates, which were used to calculate emission rates, were affected by factors including, but not limited to, indoor and outdoor temperatures, building design, manure handling system, and animal numbers and sizes. These differences between facilities contributed to the variation seen in the derived emission rates (Table 2).

Table 2. Derived NH_3 emission rates adapted from Groot Koerkamp et al. (1998)

	Emission Rate (g/day/AU)			
Animal, Housing	**England**	**The Netherlands**	**Denmark**	**Germany**
Broilers, litter	199	100	53.0	180.
Layers, battery cages	224	39.0	51.8	14.4^{+}
Layers, deep litter/perchery	177	227	261	---
Finishing swine, slats	62.2	49.8	61.6	57.6
Finishing swine, litter	34.3	---	90.0	---
Weaning swine, slats	25.1	18.9	37.5	15.6
Sows, slats	25.2	30.8	40.8	29.1
Sows, litter	17.9	---	---	78.0
Calves, slats/group	---	27.6	---	43.1
Calves, litter	7.6^{+}	---	24.9	21.3
Beef cattle, slats	---	20.5	21.6	8.9^{+}*
Beef cattle, litter	11.5^{+}*	---	---	10.3
Dairy cattle, litter	6.2^{+}*	21.4	11.8	11.2^{+}*
Dairy, freestall	25.2^{+}*	42.5	20.2^{+}	28.0*

$^{+}$ outside NH_3 concentration $\geq$ 20% of inside concentration
* calculated from winter samples only

A recent study funded by the USDA and the Initiative for Future Agriculture and Food Systems (IFAFS), and headed by a six-state research team, began a long term project to look at continuous emissions of NH_3, H_2S, CO_2, and PM_{10} from four different types of swine operations and a poultry operation. The sites were located in Indiana, Texas, Illinois, Iowa, and Minnesota. The study was called "Air Pollutant Emissions from Confined Animal Buildings"

(APECAB). Two barns were examined at each site and a common sampling protocol was set. Preliminary results from each facility are given in Table 3 along with a facility description as taken from Heber et al. (2005), Hoff et al. (2005), Jacobson et al. (2005), Jerez et al. (2005), and Kozeil et al. (2005).

Table 3. Reported NH_3 emission rates from APECAB study (uncertainty is ± 1 St. Dev.)

State	**Facility type**	**Barn 1 Emission rate (g/day/AU)**	**Barn 2 Emission rate (g/day/AU)**
Indiana	Poultry, caged layer barns	279 ± 33.8 (± 95% CI)	298 ± 43.8 (± 95% CI)
Illinois	Swine breeding and farrowing; shallow pit, pull and plug manure removal	12.3 ± 5.1	11.7 ± 6.7
Iowa	Swine finishing; deep pit	50.2 ± 21.3	60.6 ± 27.4
Minnesota	Swine gestation (Barn 1) and breeding (Barn 2)	15.5 ± 6.8	22.1 ± 5.9
Texas	Swine finishing; shallow pit, pull and plug manure removal	37.5 ± 13.2	38.5 ± 20.0

Arogo, Westerman, and Heber (2003) provided a review of methods for estimating NH_3 fluxes, factors affecting emissions, and the main sources (housing, manure storage/treatment, and land application) from swine operations. Arogo et al. (2006) provided a review of these same topics for swine, poultry, dairy, and beef cattle operations. In both reports, numerous literature values of emissions from animal housing in both the U.S. and Europe were discussed and presented in tabular form, along with emissions from waste storage and land application. Emission rates measured in the U.S. for a variety of livestock facilities and reported by Arogo et al. (2006) may be found in Table 4.

Table 4. Ammonia emission rates reported for the U.S. from livestock housing, adapted from Arogo et al. (2006)

Species/Type	**Housing/Manure Management**	**Location**	**Season**	**Emission Rate**	
				Average	**Range**
Poultry					
broiler	Litter	Delmarva Peninsula	Summer	716 g/d/AU *	182 – 1450 g/d/AU *
broiler	Litter	Arkansas	Oct. – April	88.2 g/d/AU *	
layer	Cage/high rise	Iowa	Jan. – Dec.	262 g/d/AU *	204 – 295 g/d/AU *
layer	Cage/belt	Ohio	Mar. – July	303 g/d/AU *	
layer	Cage/deep pit	Ohio	Mar. – July	482 g/d/AU *	

* Emissions on a per AU (500 kg live weight) basis calculated using the following average animal weights given in U.S. EPA (2004a): Beef = 926 lb/head; Dairy = 880 lb/head (1 cow, 1 heifer, 1 calf); Broiler = 2 lb/head, Layer = 4 lb/head

Redwine et al. (2002) studied PM_{10} and ammonia concentrations and ventilation rates at a four barn, broiler operation in Texas during the summer and winter. Each barn housed 27,500 birds from hatching to market weight (~ 49 days). Wood shavings were used for floor litter and the indoor temperature was maintained between 20 and 31 ˚C. The NH_3 emission rates increased with bird age. Summer and winter NH_3 emission rates ranged from 1426 to 50520 g/day/barn and 912 to 45432 g/day/barn, respectively. The article did not provide sufficient information to calculate emission rates normalized by the AU. However, Lacey, Redwine, and Parnell (2003) utilized these facility emission rates to report total particulate and ammonia emissions per bird per growing cycle. They used data collected during the summer, the period expected to produce the highest emission rates due to increased temperature and ventilation, to yield the maximum emission rate for comparison with reporting requirements by the CAA. The resulting emission rates can be seen in Table 15 compared with other values compiled by Lacey, Redwine, and Parnell. The difference in climate between central Texas and Europe, the time of year in which measurements were taken, and differing management techniques were cited as potential explanations for the higher emission rates measured in the US.

A multi-state research team funded by the USDA IFAFS program examined poultry operations in the U.S. to build a database of poultry ammonia emission rates (Xin et al., 2003). Preliminary results from laying hen and broiler houses were reported by Liang et al. (2003) and Wheeler et al. (2003) at the third Air Pollution from Agricultural Operations conference. Both studies utilized a portable monitoring unit (PMU) designed to measure NH_3, CO_2, and static pressure. Two electro-chemical NH_3 loggers were used for data redundancy. The systems were operated on a purge air/sample air cycle to eliminate errors from instrument saturation. The purge air/sample air times varied

Table 5. NH_3 emission rates given by Lacey, Redwine, and Parnell (2003) for broilers on litter

Location	**Emission Rate (g/day/AU)**	**Emission Rate (g/day/bird**)**
US*	307.2	0.63
UK	117.6	
UK	204	
UK+	199.2	0.48
The Netherlands+	100.8	0.27
Denmark+	52.8	0.21
Germany+	180	0.44

UK	45.6	
UK	148.8	
Ireland	148.8	

* From calculations reported in Lacey, Redwine, and Parnell (2003)
[+] From Groot Koerkamp et al. (1998), presented previously
** Assuming an average weight of 2 lb/broiler (U.S. EPA, 2004a), there are about 552 broilers per 500 kg live animal weight (1 AU)

according to NH_3 concentration range. Sample periods were 48 hours or more in length.

The following papers present peer-reviewed results from these studies.

Final results from the study of laying hen houses in Iowa (IA) and Pennsylvania (PA) were reported by Liang et al. (2005) for manure belt (MB) and high-rise (HR) housing. Manure was removed daily in an IA MB facility and twice weekly at two MB facilities in PA. Manure from all HR facilities was removed annually. The type of housing appeared to be a very important factor in ammonia emission rates. High-rise house rates averaged 0.90 ± 0.037 g/bird/d (306 ± 16 g/d/AU) in IA and 0.83 ± 0.099 g/bird/d (275 ± 36 g/d/AU) in PA; manure belt house rates averaged 0.054 ± 0.0048 g/bird/d (17.6 ± 1.5 g/d/AU) for daily manure removal and 0.094 ± 0.019 g/bird/d (30.8 ± 5.9 g/d/AU) for semi-weekly manure removal. Findings suggest both a daily and a seasonal variation in emission rates, with higher emission rates occurring during the day and during the summer in both housing systems. Emission rates calculated for both European and U.S. layer facilities, with a variety of housing and manure treatments, were given by Liang et al. (2005) and are presented in Table 6 along the results from this study.

Table 6. Layer housing NH_3 emission rates adapted from Liang et al. (2005)

Country	**House Type**	**Season**	**Manure Removal Interval**	**Emission Rate (g/d/AU)**
England	Deep-pit	Winter	N/A	192
England	Deep-pit	Summer	N/A	290
England	Deep-pit	N/A	N/A	239
U.S. (Ohio)	High-rise	March	Annual	523*
U.S. (Ohio)	High-rise	July	Annual	417*
U.S. (IA & PA)+	High-rise	All year	Annual	298
The Netherlands	Manure belt	N/A	Semi-weekly w/ no drying	31
The Netherlands	Manure belt	N/A	Weekly w/ drying	28
Denmark	Manure belt	All year	N/A	52
Germany	Manure belt	All year	N/A	14
The Netherlands	Manure belt	All year	N/A	39
England	Manure belt	All year	Weekly	96
England	Manure belt	All year	Daily	38
U.S. (IA & PA)+	Manure belt	All year	Daily w/ no drying	17.5
U.S. (IA & PA)+	Manure belt	All year	Semi-weekly w/ no drying	30.8

* Liang et al. calculated this number based on reported emission rate in g/hen/yr and assuming a hen body mass of 1.5 kg
+ Results from Liang et al. (2005)
N/A = information not available

Wheeler et al. (2006) examined ammonia emissions from 12 broiler houses over a one-year period. Two houses at each of two locations in PA and four houses at each of two locations in Kentucky (KY) were monitored. One facility in PA provided fresh litter for each flock while the other facilities replaced the litter once per year; in addition, a pH-reducing litter treatment was used in some houses utilizing built-up litter, but all built-up litter houses were grouped for comparison with houses using new litter. A flock was removed at the age of 42 –

63 days, depending on the facility, yielding emission data on 5 to 6 flocks per facility. Researchers found seasonal trends in ventilation exhaust NH_3 concentration and ventilation rates, but not in house emission rates. Based on a per bird basis only, the emission rates increased with increasing age and at all facilities birds of similar age exhibited similar emission rates. Based on a per AU, emission rates on fresh litter were almost zero for the first 6 days at all facilities, but new flocks with built-up (reused) litter had very high emission rates of 400 ± 200 (standard deviation) g/d/AU for the first 14 days. After 14 days, the average emission rate across all flocks was 225 ± 50 (± one standard deviation) g/d/AU. Table 7 lists the results of this study compared with results from other broiler house studies found in literature. Wheeler et al. (2006) stated that lower reported emission rates from broiler houses in Europe were possibly due to the following management practices that differ from those employed in the U.S.: 1) litter was usually changed between each flock, and 2) birds were slaughtered at a lower weight.

A comparative study of broiler emission rates during summer conditions from different housing types was conducted by Siefert and Scudlark (2006) on the Delaware/Maryland peninsula. Downwind concentrations were measured at both

Table 7. Broiler on litter emission rates given by Wheeler et al. (2006)

Location	**Sample Age [Market Age] (d)**	**Final Weight (kg)**	**Litter**$^+$	**Emission rate**		**House/ Flocks**	**Seasons**
				(g/d/ bird)	**(g/d/ AU)** $^{\#}$		
U.S. (PA & KY)*	1-45 [42]]	2.2	N	0.47	259	2 / 5 each	All
U.S. (DE)	2-42 [42]	2.2	B, T	0.65	358	2 / 6 each	All

U.S. (TX)	1-53 [49]	2.5	B, T	0.76	419	4 / 6 each	All
	1-55 [63]	3.3	B, T	0.98	540	4 / 5 each	All
	29-37 [42]	N/A	B?	1.18	650	1 / 1	Spring, Summer
	8-47 [49]	2.4	B	0.63	347	4 / 3 each	Summer, Fall
U.S. (TN)	1-42 [42]	2.3	B	0.92	507	1 / 9	All
Germany & Czech Rep.	13-30 [32]	1.6	N?	0.09	49.6	2 / 1	Winter
U.K.	1-32 [32]	1.9	N	0.11	60.6	1 / 1	Summer
U.K.	24-35 [32]	1.1 W, 1.4 Su	N?	0.26	143	4	Winter, Summer

* results from study conducted by Wheeler et al. (2006)
$^{+}$ Litter: N = new, B = built-up, T = treated
$^{\#}$ emission on a per AU (500 kg live weight) basis calculated using average bird weight of 2 lb/bird (U.S. EPA, 2004a)
? not explicitly stated, but inferred from data, statements in article, or common practice
N/A = not available

facilities using a three dimensional array of Ogawa passive samplers and emission rates were determined by coupling the measured concentrations with a LaGrangian-based, inverse Gaussian dispersion plume model. The first study, which was reported by Siefert et al. (2004), involved a side-wall ventilated house and yielded emission rates with an mean of 1.18 g/d/bird and a range of 0.27 – 2.17 g/d/bird. The second study was of a tunnel-ventilated broiler house under similar summer conditions. The mean emission rate from this study was 0.11 g/d/bird, a factor of 10 lower. Siefert and Scudlark (2006) suggested the difference was mainly due to the difference in litter moisture content. Greater air flow in the tunnel-ventilated house dries out the litter more effectively while maintaining adequate air temperature, whereas misters, which increase litter moisture, are required in the side-wall ventilated house to maintain adequate air temperature. While designed for better air movement control, an additional advantage of the modern tunnel-ventilation method may be decreased ammonia emission rates.

As a review, the ranges of poultry ammonia emissions rates presented in this section are summarized in Table 18, with emission rates reported for Europe and the United States separated for comparison. In the absence of multiple data points per housing/manure management type and species, the reported average NH_3 emission rate is given. There exists a large variation in emission rates found in literature for all species, even for those utilizing the same housing/manure management techniques. This suggests that there are other factors that may have a significant effect on reported emission rates, including, but not limited to, measurement technique, temperature, moisture content, pH, etc. For poultry housing/manure management techniques used in both U.S. and Europe, the emission rates reported in Europe tend to be smaller in both range and magnitude, where the maximum reported emission rates are under 300 g/d/AU for Europe, while maximum emission rates in the U.S. are between 300 and 1450 g/d/AU.

Nitrous Oxide

Nitrous Oxide is a product of both nitrification and denitrification. Pahl et al. (2001) demonstrated that there was a large variation in the split between nitrification and denitrification processes as the source of N_2O production. Their results showed that specific conditions could favor nitrification or denitrification to be the principal source of N_2O emissions: (i) through denitrification under oxygen inhibition; or (ii) through nitrification in aerobic systems, in combination with the presence of nitrification products. Therefore, N_2O can be released at any stage of livestock production where conditions favor these processes (Chadwick et al., 1999). Leaching, absorption by plants, or utilization by microorganisms indirectly influences the production of N_2O.

Nitrous oxide emissions are an environmental concern. (Houghton et al. 1992) stated that N_2O is approximately 200 times more efficient than CO_2 in absorbing infrared radiation. Methane, another strong greenhouse gas, is only 26 times more efficient than CO_2 in absorbing infrared radiation. Furthermore, N_2O contributes to the reduction of ozone in the stratosphere through the photochemical decomposition of N_2O to NO (Finlayson-Pitts et al., 2000).

Data on N_2O emissions from animal housing is limited. (Chadwick et al. 1999) summarized N_2O emissions from animal housing in the U.K. Nitrous oxide emissions varied from 0.4 to 26 g N_2O AU^{-1} day^{-1}. The lowest emissions values were from swine housing and the highest were from poultry housing.

Hydrogen Sulfide

Hydrogen sulfide is formed by bacterial sulfate reduction and the decomposition of sulfur-containing organic compounds in manure under anaerobic conditions (Arogo et al., 2000). H_2S gas is colorless, heavier than air, highly soluble in water and has the characteristic odor of rotten eggs at low concentrations. At concentrations around 30 ppb the H_2S odor can be detected by over 80% of the population (Schiffman et al., 2002). The U.S. OSHA has implemented a 10 ppm limit for indoor 8-hour H2S exposures to protect human worker health (ACGIH, 1992). Most human health problems associated with hydrogen sulfide emissions are related to emissions from paper mills, refineries, and meat packing plants (Schiffman et al., 2002). Currently, there is only circumstantial evidence relating emission of hydrogen sulfide from poultry to human health.

Although there are health risks associated with high concentrations of H_2S, concentrations are usually very low in and around poultry housing as compared to concentrations of CO_2 and NH_3. McQuitty et al. (1985) reported on H_2S concentrations in three commercial laying barns under winter conditions. No detectable traces of H_2S were found in two barns and a maximum H_2S concentration of 30 ppb was measured in the third barn.

Gay et al. (2002) reported on H_2S emissions rates from 80 farms in Minnesota. Mean H_2S emissions varied from 0.03 to 0.35 g H_2S m^{-2} day^{-1} from poultry housing. More data is needed to identify baseline H_2S emissions from poultry housing.

Dust

Particulates in and around poultry production sites include soil particles, bits of feed, hair or feathers, dried feaces, bacteria, fungi, and endotoxins (Koon et al., 1963, Anderson et al., 1966, Curtis et al., 1975b, Heber and Stroik, 1988, Curtis et al., 1975a, Heber et al., 1988). Sources include poultry birds, feed storage and processing sites, floors, manure storage and handling equipment, open lots, compost sites, and other elements of animal agriculture systems.

Feed was found to be the primary component of the dust in animal housing (Curtis et al., 1975b, Heber and Stroik, 1988, Heber et al., 1988). Soil particles from open unpaved feedlots also contribute to dust levels (Alegro et al., 1972, Sweeten et al., 1988). Dust emissions from feedlots depend on soil texture, rainfall, feedlot surface moisture content, wind speed, season, and other factors.

Flooring design has been shown to significantly affect the airborne dust levels; solid floors have much higher levels than open-mesh floors (Carpenter and Fryer, 1990, Dawson, 1990). The latter allow feces and soiled bedding to fall below the floor level and minimize dust generated by animal activities.

There is little research on dust emission factors from animal agriculture facilities and their environmental impact. Most studies have focused on dust concentrations and characterization in swine (Barber et al., 1991, Maghirang et al., 1997) and poultry (Jones et al., 1984, Carpenter et al., 1986) housing rather than emissions.

Impacts of particulate matter and bioaerosols on human health are discussed in detail in the white paper on health effects of aerial emissions from animal production and waste management systems (Schiffman et al., 2002).

Wathes et al. (1997) measured dust emissions from broiler and a layer facility in the U.K. Table 8 summarizes the results obtained by Wathes et al. (1997).

Table 8. Emission of dust by poultry houses (Wathes et al., 1997)

Type	Season	Inhalable dust ($g\ AU^{-1}\ h^{-1}$)	Respirable dust ($g\ AU^{-1}\ h^{-1}$)
Layers	Winter	0.9	0.24
Broilers	Winter	5.2	0.60
Layers	Summer	1.1	0.09
Broilers	Summer	8.2	0.88

Takai et al. (1998) reported on inhalable (includes all size particles) and respirable (particles that are less than 5 microns) dust emissions from various poultry facilities in four European countries (Table 9). Emissions were estimated from mean daily dust concentrations near air outlets and the daily mean ventilation rate through the buildings.

Table 9. Mean inhalable and respirable dust emission factors from English, Dutch, Danish, and German Poultry buildings (Takai et al., 1998).

Specie	**Mean inhalable dust ($g\ AU^{-1}\ h^{-1}$)**	**Mean respirable dust ($g\ AU^{-1}\ h^{-1}$)**
Poultry Housing		
England	3.14	0.37
The Netherlands	3.64	0.72
Denmark	3.51	0.62
Germany	2.12	0.25
Overall mean	3.19	0.50

Statistical analysis indicated that both country and housing type were significantly different for inhalable dust emissions (Takai et al., 1998), although this could be an artifact from measurement system bias. Inhalable dust emissions from cattle buildings were not affected by season. There were significant seasonal effects on inhalable dust emissions from both swine and poultry housing. The highest dust emissions were from percheries (laying hen facilities with litter flooring and perches) in the Netherlands and Denmark, and from broiler houses in England and the Netherlands (Takai et al., 1998). Animal activity level, stocking density, spilled feed, bedding material selection, and humidity levels affected dust emissions. The significance of country, season and other factors suggests that results from Takai et al. (1998) are unlikely to accurately describe dust emissions from animal buildings in the United States.

METHODOLOGY

<u>Building description</u>

A commercial layer farm in northern Utah was selected for the study. The farm consisted of 12 broiler houses. No other livestock were present on the premises. Two Houses were selected for the study; one of the houses a high rise (barn 5), was 13.5 x 158 m (44.3 x 518.4 ft) long and held approximately 53,800 birds. The other house (manure belt) was also 13.5 x 158 m (44.3 x 518.4 ft) long (barn 4) and held 118,700 birds. The distance between the two selected barns is 17.5m. All houses were oriented east-west and mechanically ventilated. Each of the four houses has nine fans facing north; the fans on the West and East barn 5 were circular with sixteen of the fans having diameters of about 61 inches and two middle fans with diameter of 49 inches. The fans on the West and East of barn 4 were square shaped with length of about 62 inches. The overall total number of fans sampled is 36 fans, 16 for each management technique. The ventilation systems were thermostatically controlled (The fans come on automatically based on the temperature of the barn).

Figure 2. External view of Barn 5 (High Rise)

Figure 3. External view of Barn 4 (Manure Belt)

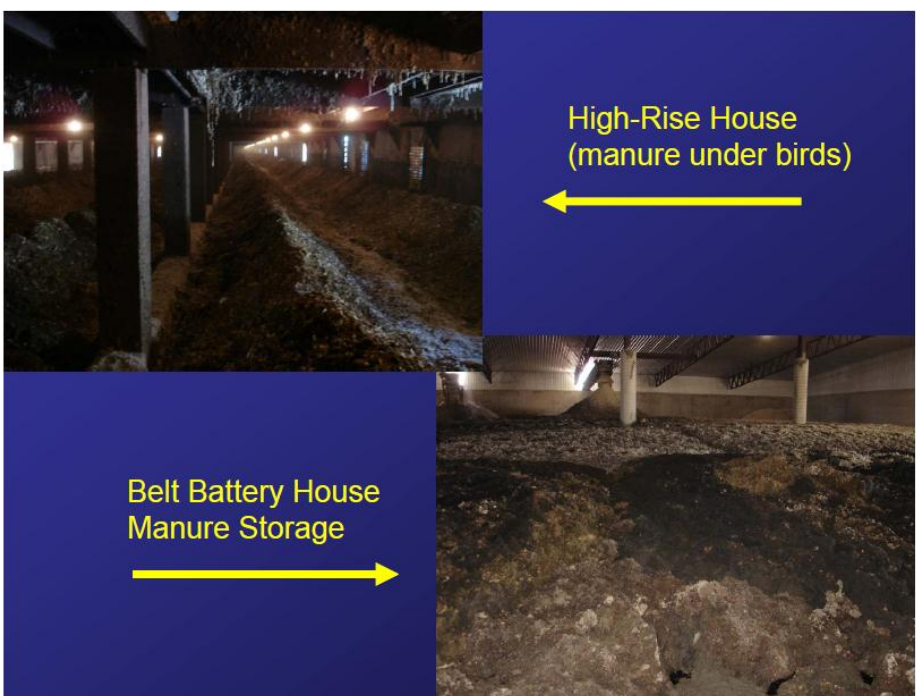

Figure 4. Internal view of the two management systems examined in the study.

Beginning June, 2008, continuous PM and specific gaseous pollutant emissions were measured for about six months. Emission rates of particulate matter with aerodynamic diameter equal and smaller than 10 micro (PM_{10}), 2.5 micron ($PM_{2.5}$) and total suspended particulate (TSP) were measured. A mobile air quality lab was used to host equipment and data acquisition systems.

MiniVols and OPCs were used concurrently to continuously monitor Dust concentrations in the building exhaust air and ambient air. The ventilation rate was continuously monitored by recording the number of active fans and their rotation speed, using induction sensors placed on every ventilation fan in the barns and correlating these values with the airflow rate using (Dwyer VT 140 thermo-anemometer) on-site hand-held anemometric measurements, taken for each monitoring cycle, for each ventilation step. Figure 5 shows the location of the induction sensor to the fan motor. The sensor counts the number of times the fan spoke passes in front of it and this value is automatically recorded every 10 minutes. The counts recorded are then converted to velocity (RPM) by dividing it by the number of arms of the spokes of the fan wheel and the time of response which is 10 minutes. The velocity in RPM is then converted to air flow rate in ft^3min^{-1} by employing the individual fan calibration equation for each of the 36 fans. The velocity was measured at the fan's shroud face roughly following spacing dictated by the U.S.E.P.A.s Method 1 for stack sampling. The method stipulates the use of the shroud's diameter for the circular shroud and area for the rectangular shroud. The characteristic location of the 16 traverse points used for the two types of fan shroud is shown in figure 6.

Figure 5. Location of induction sensor of fan motor

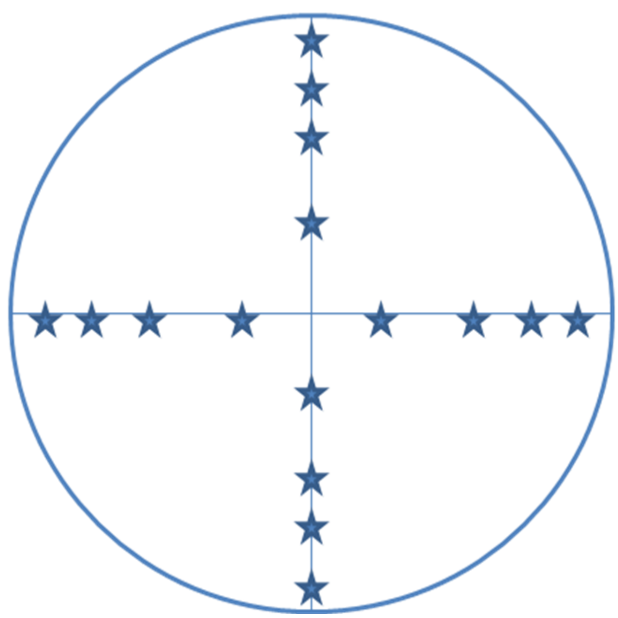

Figure 6a. Traverse points in a circular shroud.

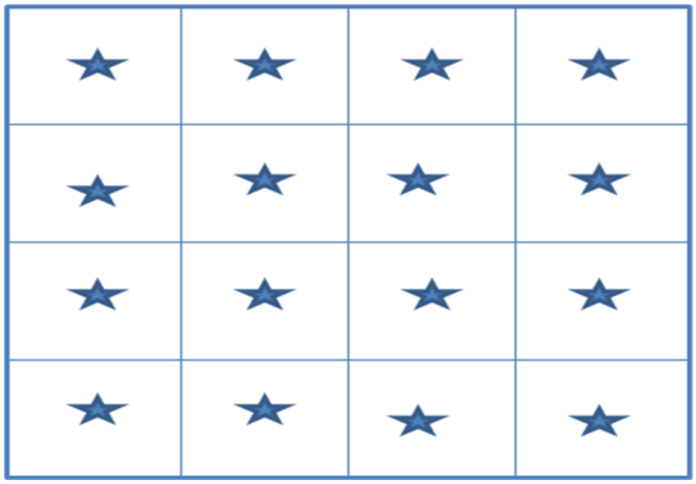

Figure 6b. Traverse points in a rectangular shroud.

Table 10. Sampling traverse points for circular and rectangular shrouds according to U.S.E.P.A.s Method 1 for stack sampling.

Barn 5 West	Diameter (in)										
Fan				Traverse Points							
	Horizontal	Vertical	Avg.diam	1	2	3	4	5	6	7	8
WF1	60.5	61.1	60.8	1.9	6.4	11.8	19.6	41.2	49.0	54.4	58.9
WF2	61.5	60.1	60.8	1.9	6.4	11.8	19.6	41.2	49.0	54.4	58.9
WF3	61.5	61.0	61.3	2.0	6.4	11.9	19.8	41.5	49.4	54.8	59.3
WF4	60.5	61.3	60.9	1.9	6.4	11.8	19.7	41.2	49.1	54.5	58.9
WF5	49.0	47.3	48.1	1.5	5.1	9.3	15.5	32.6	38.8	43.1	46.6
WF6	61.3	60.0	60.6	1.9	6.4	11.8	19.6	41.0	48.9	54.3	58.7
WF7	60.4	59.4	59.9	1.9	6.3	11.6	19.3	40.5	48.3	53.6	58.0
WF8	60.6	61.3	60.9	2.0	6.4	11.8	19.7	41.3	49.1	54.5	59.0
WF9	59.5	59.5	59.5	1.9	6.2	11.5	19.2	40.3	48.0	53.3	57.6
Barn 5 East											
EF1	61.0	60.5	60.8	1.9	6.4	11.8	19.6	41.1	49.0	54.4	58.8
EF2	61.0	60.3	60.6	1.9	6.4	11.8	19.6	41.0	48.9	54.3	58.7
EF3	60.3	60.6	60.4	1.9	6.3	11.7	19.5	40.9	48.7	54.1	58.5
EF4	61.0	61.0	61.0	2.0	6.4	11.8	19.7	41.3	49.2	54.6	59.0
EF5	47.5	48.5	48.0	1.5	5.0	9.3	15.5	32.5	38.7	43.0	46.5
EF6	60.0	60.3	60.1	1.9	6.3	11.7	19.4	40.7	48.5	53.8	58.2
EF7	60.3	60.3	60.3	1.9	6.3	11.7	19.5	40.8	48.6	53.9	58.3
EF8	60.5	60.5	60.5	1.9	6.4	11.7	19.5	41.0	48.8	54.1	58.6
EF9	59.8	61.3	60.5	1.9	6.4	11.7	19.5	41.0	48.8	54.1	58.6

Barn 4 East/West				
Square Fans	Length	Width	Area (in^2)	Area (ft^2)
All	53.75	53.8	2889.1	20.1

The temperature and relative humidity were monitored constantly at four different measurement points inside the houses, with microdataloggers (HOBO® H8 Pro, ONSET Computer Corporation). The pollutant gas emission factors were determined at the end of each monitoring period by multiplying the housing ventilation rate by the difference in concentration between the point of emission (an average of two measurements in the manure belt house and high- rise house (east and west sides)) and the background ambient concentration.

Figure 7. Spatial layout of the houses and the sampling sites.

All the tunnel ventilation fans were on the east-west end of the houses. Air sampling lines fitted with a particle filter were placed inside barn 4 and 5 (to continuously measure ammonia, hydrogen sulfide, carbon dioxide and water vapor) 4.6 m (15 ft) from the tunnel fans to measure the exhaust concentration). Figure 8 shows the schematic layout of the monitoring site specifying the approximate location of sampling points and important house dimensions. The

MAEMU (mobile air emission monitoring unit) accommodates the other entire instrument that assists in effective data measurement and acquisition.

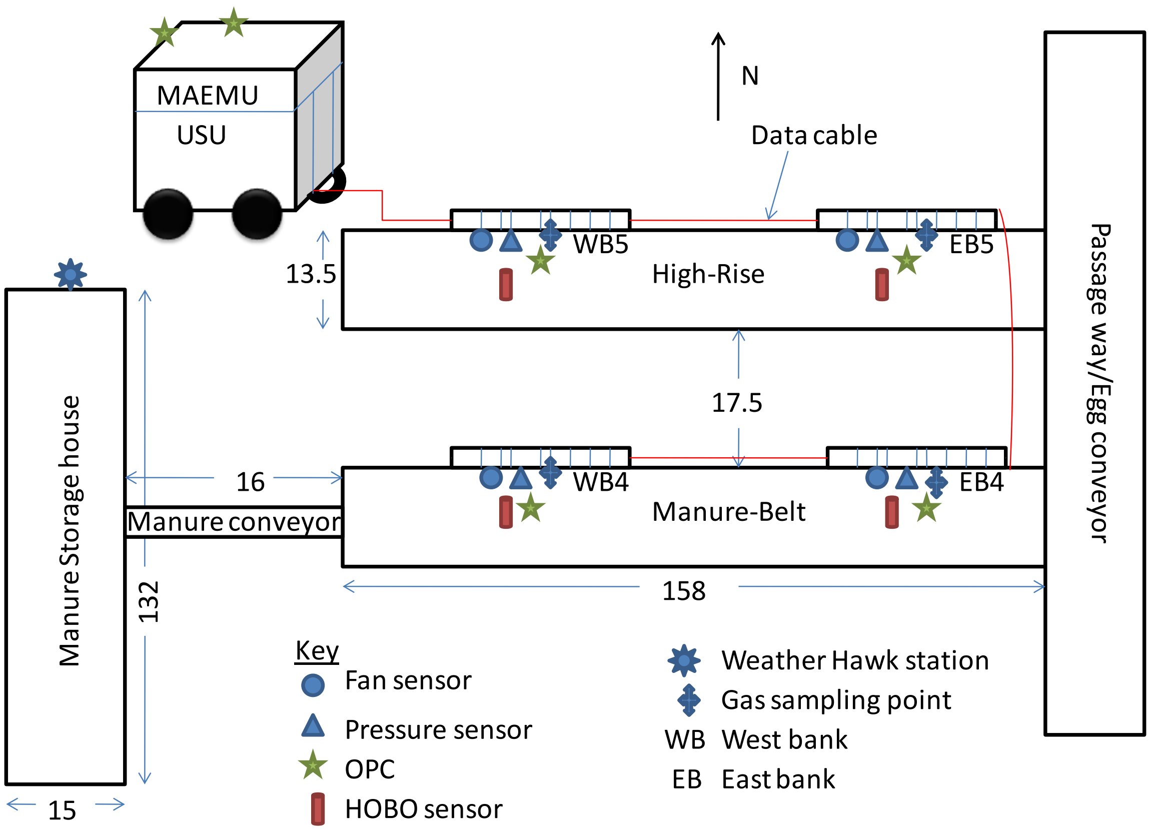

Figure 8. Schematic layout of the sampling site.

Particle Mass Concentration Measurement

At each site, portable Air Metrics MiniVol PM_1/$PM_{2.5}$/PM_{10}/TSP samplers were used to determine the point-specific mass concentrations. Four MiniVols and the four OPCs were initially placed in one of the barns (West barn 5) for one week at a distance of about 4ft from the ground level to collect data and to calibrate the OPCs in order to be able to reliably collect data continuously. Figure 7 shows the picture of the array of the OPCs and MiniVols in the poultry barn. The OPCs were then moved to four different sampling points, two in each barn tagged east barn 4 (EB4), west barn 4 (WB4), east barn 5 (EB5) and west barn 5 (WB5). Two OPCs were placed outside at the top of the trailer which is at a distance of about 7ft from the ground level to measure the background particulate concentration.

Figure 8. Array of OPCs and MiniVols in the poultry barn.

The calibration of the OPC with the MniVols is a critical part of the project which allows for reliable continuous particulate measurement. The MiniVols can be programmed to operate for a desired time period and consist of a size-segregating sample inlet (the impactor), a 47 millimeter (mm) filter cartridge, and a pump. The sample inlet can be equipped with different impactor heads, which separate particles using inertial impaction based on the particle's aerodynamic diameter. The MiniVols are designed to operate at five liters per minute (L/min) and collect the size separated particle matter on 47 mm Teflon filters that were pre-weighed and pre-conditioned at Utah State University's (USU) Utah Water Research Laboratory (UWRL).

After the filters had been used in the MiniVols they were returned to the UWRL for post-test conditioning and a final weight determination. Filter weights were measured in milligrams (mg) to three decimal places (i.e. 1 microgram (μg)) using a Mettler Type MT5 balance (Mettler Instrument Corp.). The final filter weights reported were the average of three consecutive weights within ±2.5 μg of the mean, which translates to a minimum system detection limit (MDL) of 0.36 $\mu g/m^3$ on a 24 hr average sampling time. Once the final filter weight is measured the mass of PM collected can be found by taking the difference in pre- and post-weights; then, using the air flow and run time, a mass concentration can be determined.

MetOne 9722 optical particle counters (OPC) were collocated with the MiniVol particle samplers. The OPCs provide near-real-time (20 – 60 second averaging) size distribution and particle count information, which can be used to estimate the duration and intensity of an impact by any particulate plume. The OPC operates by passing sample air through a right angle light scatter detector using a laser diode. The OPC pulls 2 L/min sheath air to protect the system's optics and a sample air flow rate of 1 L/min. The instrument counts particles and calculates their size using scattered light. A particle in the sample volume will scatter light from a laser diode, while a 60 steradian solid angle elliptical mirror, located at a right angle to the laser beam, then collects the scattered light. The collected light is converted to a voltage pulse with amplitude that is based on the scattered light intensity. The pulse is then categorized using size discriminators and counted as a particle in one of eight size bins from > 0.3 μm to > 10 μm. The OPC outputs the number of particles in the sample that fall within each bin for a set time interval. From this information, an optical size distribution can be found.

The OPC can also provide a volume concentration by assuming a radius (the geometric mean of the bin cutoff radii) for each bin and then finding the particle volume (assuming spherical particles). This gives the volume for each particle in the bin and can be multiplied by the number of particles in the bin to obtain a sample volume, or a total volume of all the particles in that bin. This can be divided by the sample volume to get a concentration of the volume of PM per volume of air. If a particle density is known, a mass concentration can then be found by multiplying the volume concentration by the density. If the density is unknown, then it can be estimated by comparing the mass concentration measured by the MiniVols with the volume concentration measured by the OPCs. An effective density can then be found by the following:

$$\rho_{particle} = \frac{C_{mass}}{C_{volume}} \tag{3}$$

where $\rho_{particle}$ is the effective particle density, with typical units (g/cm^3), and C_{mass} is the mass concentration (g/m^3) and C_{volume} is the volume concentration (cm^3/ m^3). A sample calibration graph of the OPC and the MiniVols for PM10 is presented in figure 8 while the rest may be found in Appendix A

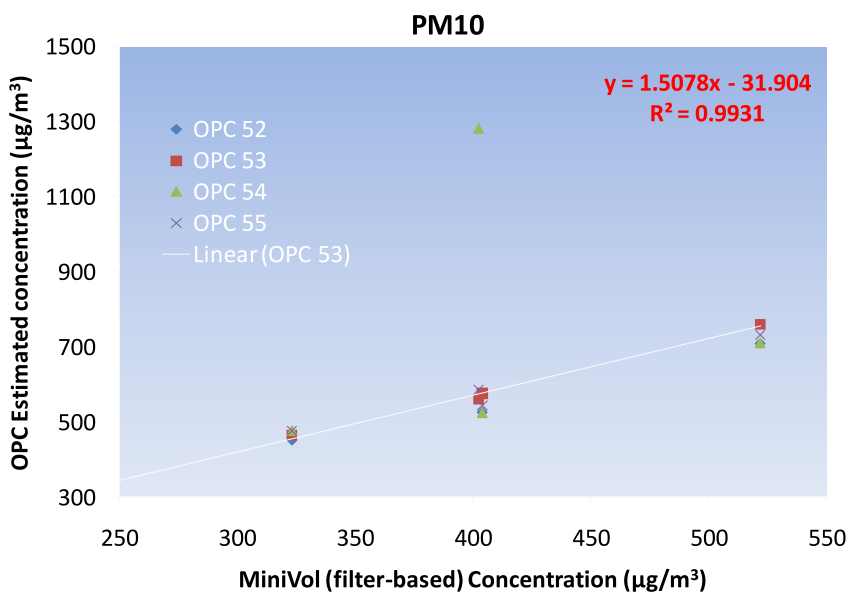

Figure 9. OPC and MiniVols calibration for PM_{10}.

Gaseous Pollutants Measurement and Manure Composition

This study utilized common instrumentation and protocol. At the measurement site, an instrument trailer was stationed between two similar, mechanically-ventilated, confined animal production buildings and emission measurements were quasi-continuous for both gas and particulate matter. The instrument trailer housed: a gas sampling system (GSS), gas analyzers, environmental instrumentation, a computer, data acquisition system, thermo-scientific vacuum pressure pumps 663U model number 420-1901, Teflon tubings and other supplies. The specific gas instrumentation is a photo acoustic Field gas Monitor INNOVA 1412 which selectively measures a wide range of gases/vapor; NH_3, EtOH, CO_2, N_2O and H_2O. There were five gas sampling points across the barns; four inside and one measuring the ambient air. The vacuum pressure pump connected to the Teflon tubings sucks the inside barn air form each sampling location and passes it through the INNOVA 1412 which detects the concentration of the gases. Six valves were coupled with the gas sampling system which alternates the measurement lines automatically with the help of a valve switching module programmed to switch the sampling line after every 1 hour. The ambient air is sampled first, followed by the inside air of the high-rise building and then that of the manure manure-belt. Water vapor interferences were eliminated by the INNOVA 1412.

Manure samples were collected for every monitoring cycle. A fixed amount of manure was taken from ten evenly distributed spots and pooled to make an average sample. In the ventilated belt house, droppings were taken on the manure belt just before discharge into the sheltered storage, while in the manure house samples were taken from the storage. The samples were analyzed for pH, total solids (TS), volatile solids (VS), total Kjeldahl nitrogen (TKN) and total ammoniacal nitrogen (TAN).

Table 11. Summary of choice of monitoring equipment

Pollutant	Monitoring Instrument
NH_3	Photoacoustic Field Gas-Monitor - Innova 1412
CO_2	Photoacoustic Field Gas-Monitor - Innova 1412
H_2S	UV Fluorescence Hydrogen Sulfide Analyzer Model 101E, Advance Pollution Instrumentation, San Diego, California
Ethanol	Photoacoustic Field Gas-Monitor - Innova 1412
Nitrous Oxide	Photoacoustic Field Gas-Monitor - Innova 1412
TSP, PM_{10}, $PM_{2.5}$	Portable Air Metrics MiniVol $PM_{2.5}$/PM_{10}/TSP samplers & Mettler Type MT5 balance (Mettler Instrument Corp.) and OPCs (Optical Particle Counters)

Meteorological Measurements

Ambient air temperature, relative humidity, wind speed, wind direction, barometric pressure, incident solar insolation and precipitation measurements were obtained from a Weather-Hawk Met-station located at the top of the manure barn (North side) 7.4m above the ground level. HOBO temperature sensors were placed in each barn to measure the inside temperature (two per barn).

RESULTS AND DISCUSSION

Emission Rate Determination

The gaseous emission rate (ER) can be expressed as the mass of the pollutant gas emitted from the poultry house to the atmosphere in a unit time period, calculated as:

$$ER = \{C_{PG} - C_{PGbackground}\} \times V_T \qquad (4)$$

Where:

ER = emission rate of pollutant gas (kg h^{-1})

V_T = Total building ventilation rate (m^3 h^{-1})

C_{PG} = concentration of the pollutant gas at the exhaust fan (ppm)

$C_{PGbackgroung}$ = background pollutant gas measurement (ppm)

The air flow rate during the monitored periods was consistently higher in the high-rise building than in the manure-belt building. This was probably due to the different type of ventilation system, which was longitudinal and more effective in the ventilation or manure-belt house. The minimum and maximum ventilation rates ranges from 1.34 m^3 $h^{-1}bird^{-1}$ to 2.89 m^3 $h^{-1}bird^{-1}$ for the high-rise building and from 0.96 m^3 $h^{-1}bird^{-1}$ to 5.30 m^3 $h^{-1}bird^{-1}$ for the manure-belt building.

Figures 10 to 16 show the average daily time course (hourly average) for the four fan banks and the total barn ventilation rate over the sampling periods for the high-rise building and the manure-belt building, respectively.

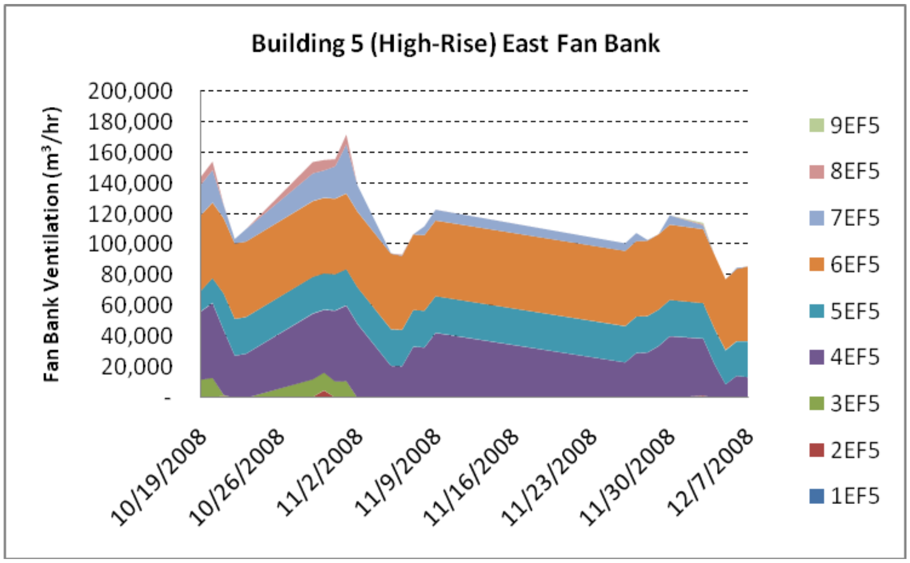

Figure 10. Average daily course (hourly average) of ventilation rate for High-Rise house showing the individual fan contribution.

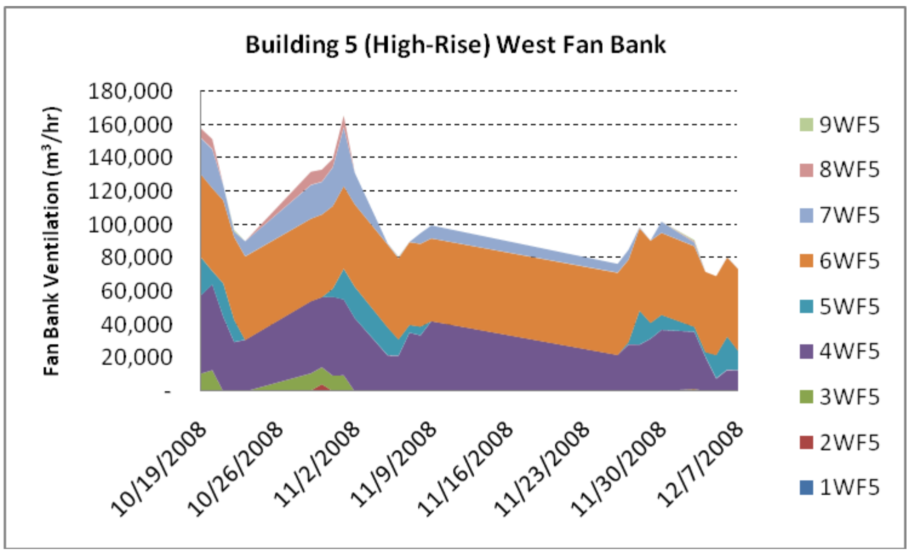

Figure 11. Average daily course (hourly average) of ventilation rate for High-Rise house showing the individual fan contribution.

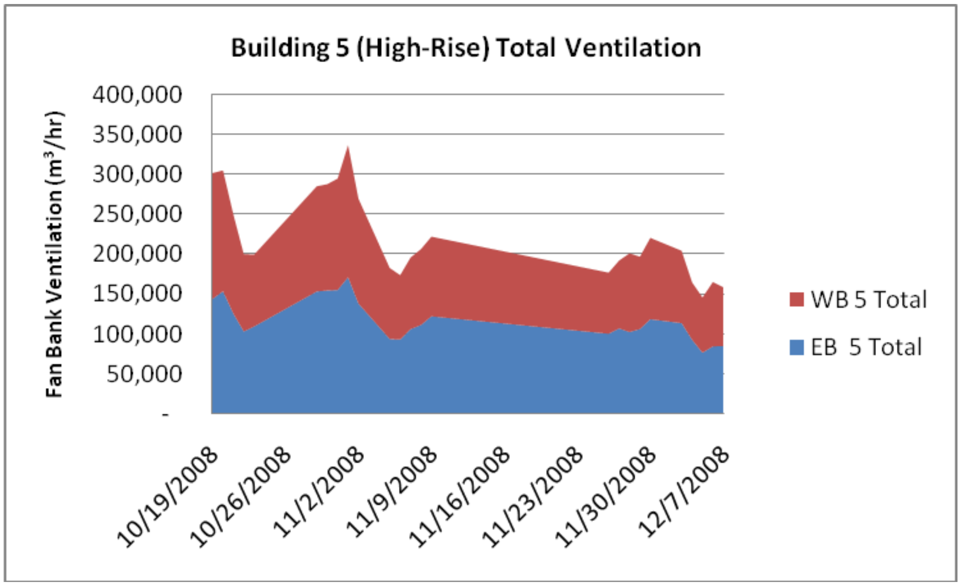

Figure 12. Average daily course of Total ventilation rate for High-Rise house

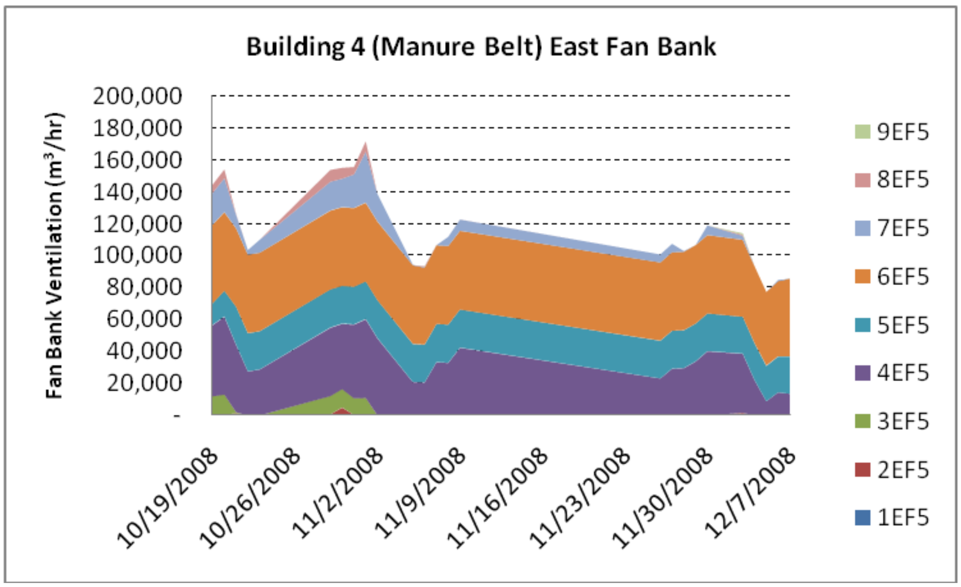

Figure 13. Average daily course (hourly average) of ventilation rate for Manure-Belt house showing the individual fan contribution.

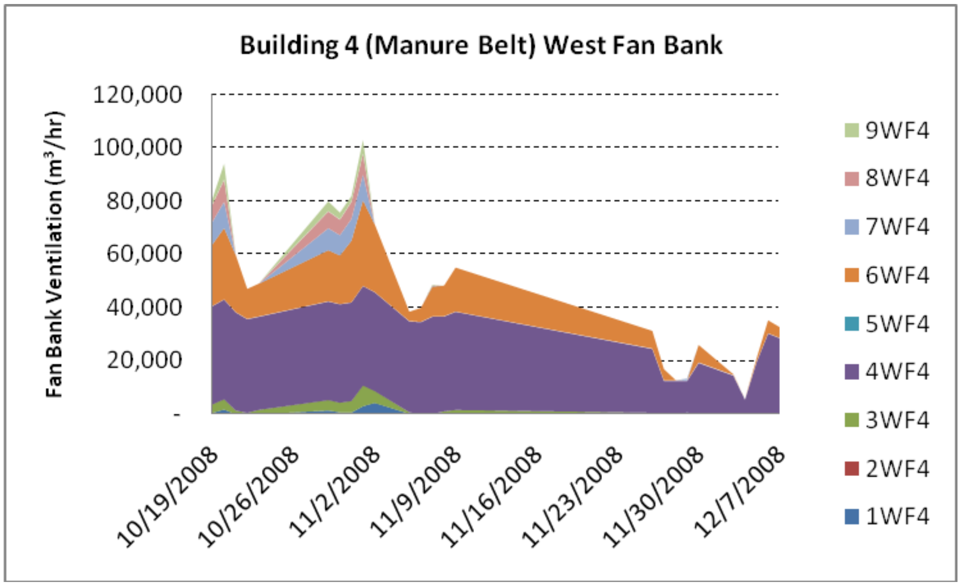

Figure 14. Average daily course (hourly average) of ventilation rate for Manure-Belt house showing the individual fan contribution.

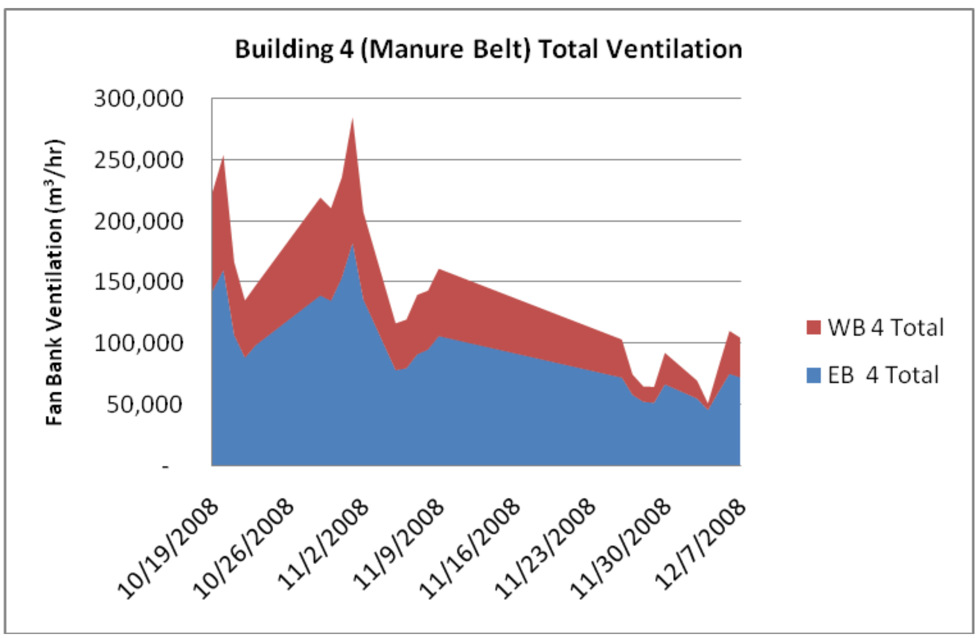

Figure 15. Average daily course of Total ventilation rate for High-Rise house

Ammonia emissions

Figure 16 shows a 24hr record of NH_3 concentration measured on the 17th September, 2008. The concentrations measured typically ranges from 0.97 to 2.10 ppm with a mean of 1.48 ppm in the exhaust air from the manure-belt building (EB4) and 5.31 to 15.47 ppm with a mean of 11.62 ppm in the exhaust air from the High-rise building (EB5). The background ambient air observed was 0.89 ppm. During the sampling period, the concentration of ammonia observed from the high-rise building is significantly higher by double digits more than the concentrations from the manure-belt building. This was probably due to the different type of management techniques. The manure stays longer in the high-rise building than in the manure-belt building where the manure is being transported to a storage house. Also, a higher degree of variability was observed in the high-rise building NH_3concentration when compared to that of the manure belt.

The ammonia concentration was quite variable for most of the sampling periods (Figure 17 and 18), but the ventilation rates for both barns were not as variable. It was observed from the plot that the inside barn NH_3 concentration was higher during the early hours of the morning when most of the fans are not running. But as the day go by, approaching noon (higher temperature) and for most part of the afternoon, the inside barn concentration reduces due to higher number of fans running thus leading to higher NH_3 emission. The ventilation rate results from the manure belt ranges from 2.11 $m^3h^{-1}bird^{-1}$ to 3.02 $m^3h^{-1}bird^{-1}$ with an average of 2.74 $m^3h^{-1}bird^{-1}$. While that of the high-rise building ranges from 1.40 $m^3h^{-1}bird^{-1}$ to 2.34 $m^3h^{-1}bird^{-1}$ with an average of 2.09 $m^3h^{-1}bird^{-1}$.

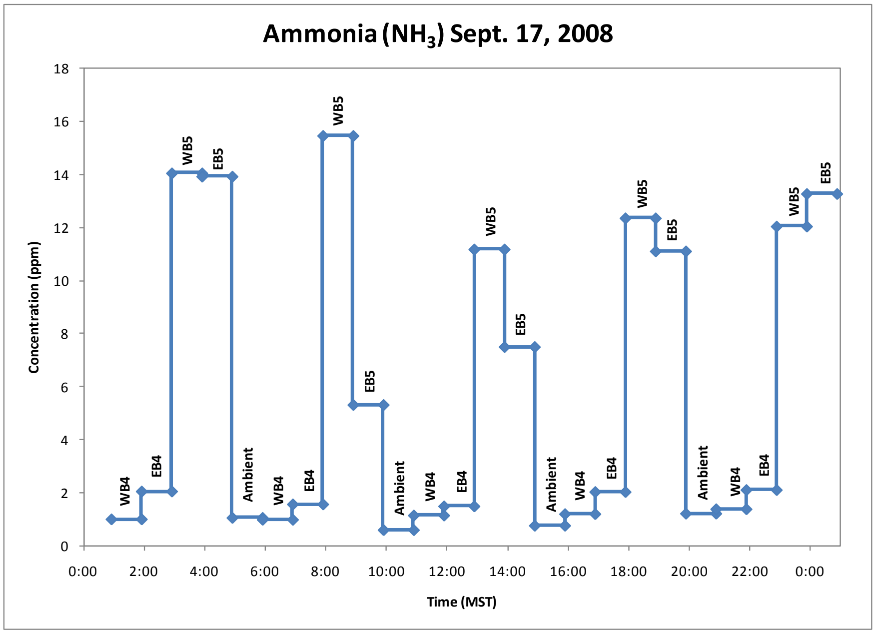

Figure 16. Average daily concentration for Ammonia

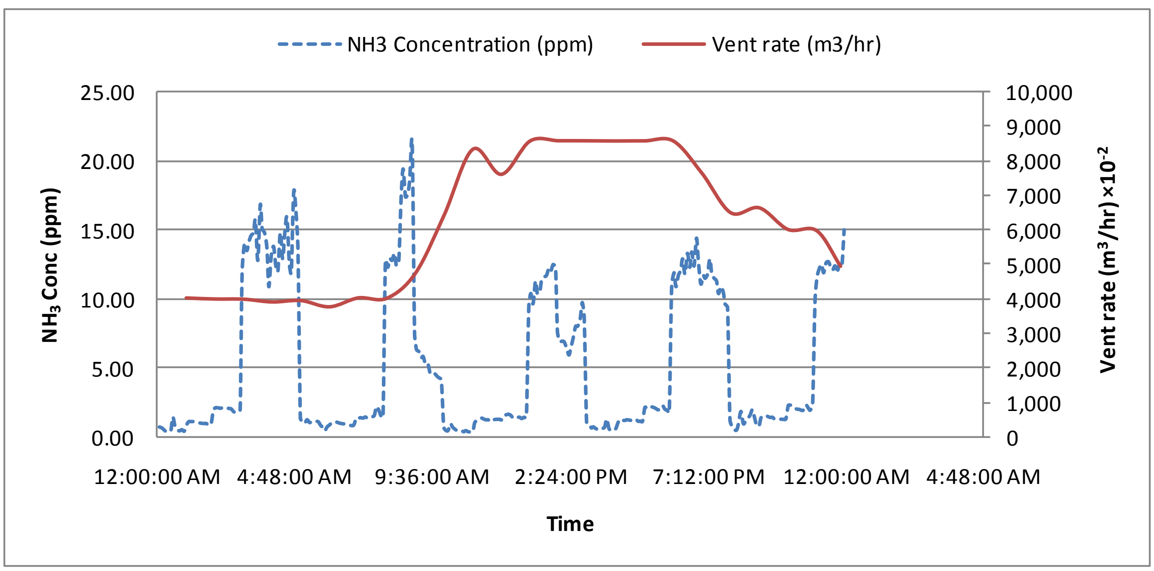

Figure 17. 24 hr Ventilation rate and ammonia concentration of building 4 (manure-belt) for the sampling period 9/17/08.

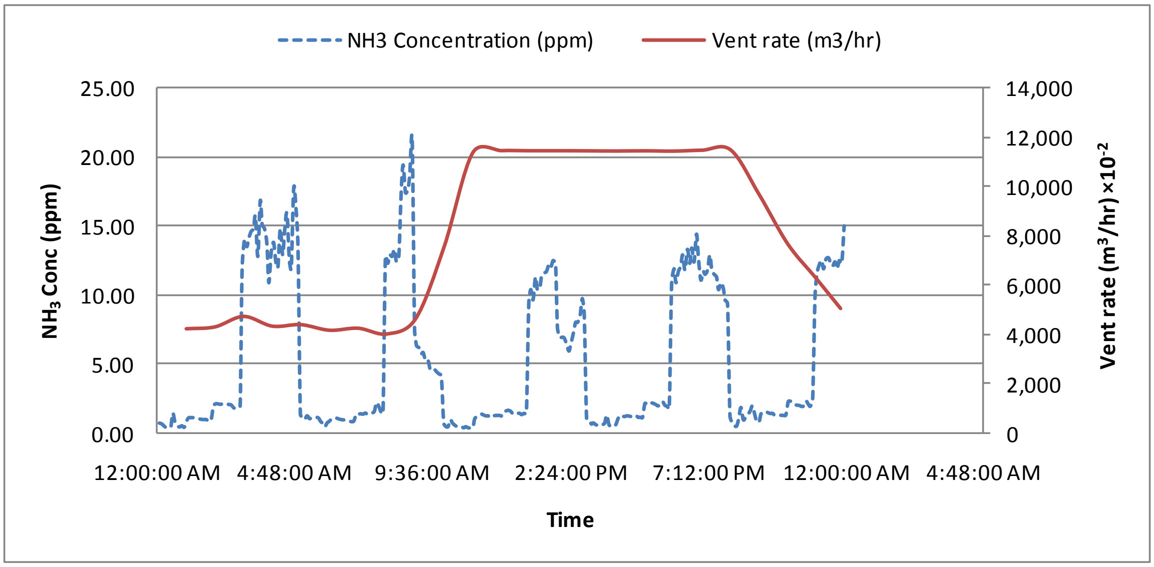

Figure 18. 24 hr Ventilation rate and ammonia concentration of building 5 (manure-belt) for the sampling period 9/17/08.

Figure 19 and 20 show the relationship between the ventilation rate and ammonia emissions for the manure-belt building and the high-rise building respectively. Based on the plots, there is no evidence suggesting increased ventilation rate leads to increased ammonia emission for the manure-belt building. But there seems to be a strong correlation pattern for the high-rise building, suggesting an increase in ventilation rate leads to an increase in ammonia emission. This difference could probably be due to the different type of ventilation technique employed.

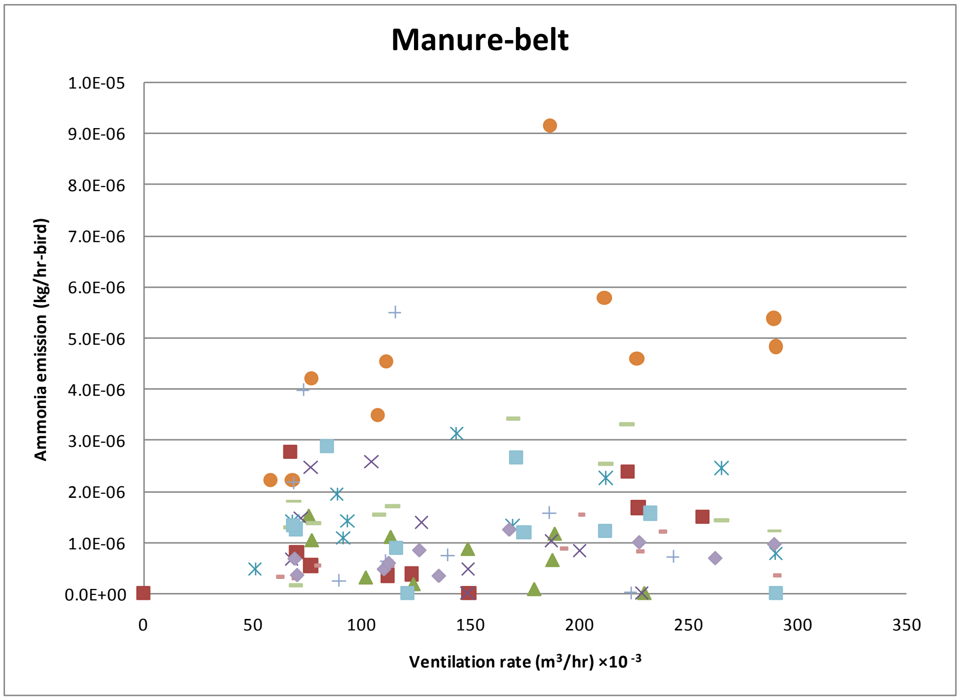

Figure 19. Ventilation rate vs NH_3 emission rate for manure-belt building (10 days sampling period)

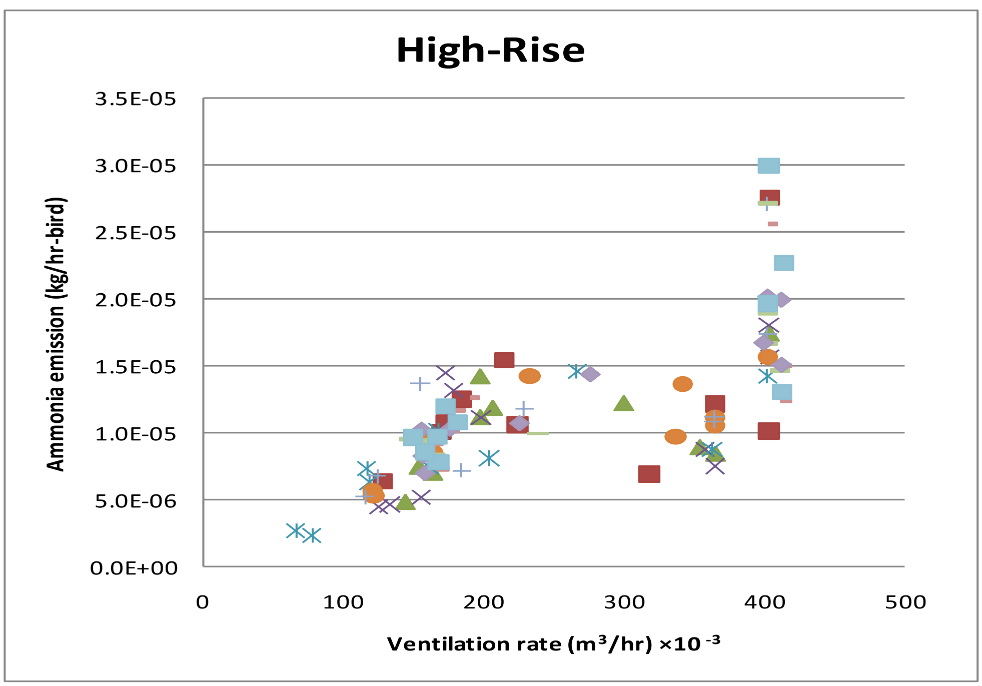

Figure 20. Ventilation rate vs NH_3 emission rate for High-Rise building (10 days sampling period)

Figure 21 shows the daily average pattern for NH_3 emission of the two management techniques. It is clear that average daily emission pattern is different. The NH_3 emission is consistently and significantly higher in the high-rise building throughout the sampling period. The NH_3 emission rate ranges from 0.09 $Ibyr^{-1}bird^{-1}$ to 0.28 $Ibyr^{-1}bird^{-1}$ with a mean of 0.22 $Ibyr^{-1}bird^{-1}$ for the high-rise building while for the manure-belt building, the NH_3 emission rate ranges from 0.01 $Ibyr^{-1}bird^{-1}$ to 0.09 $Ibyr^{-1}bird^{-1}$ with a mean of 0.03 $Ibyr^{-1}bird^{-1}$. The ammonia emission factor estimated in this study compares with the poultry ammonia emission factor stipulated by U.S.E.P.A. (2004) of 0.89 and 0.25 $Ibyr^{-1}bird^{-1}$ for wet and dry layers.

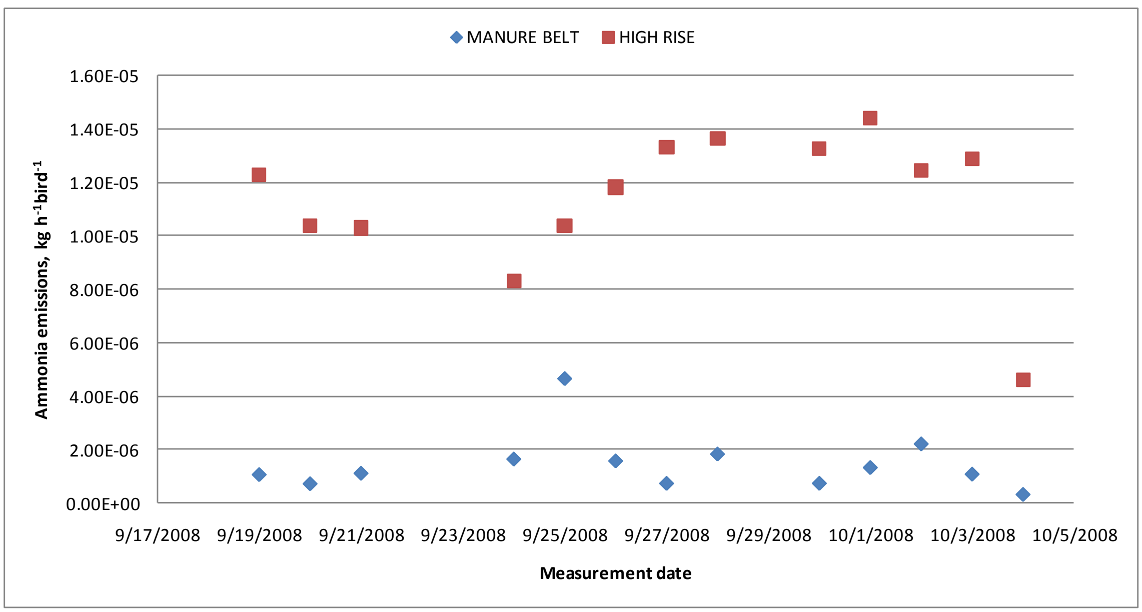

Figure 21. Daily average ammonia emission from the two different management techniques

No significant emissions were registered for ethanol, which was consistently close to zero. Only the manure-belt building recorded daily average ethanol concentrations above zero as shown in figure 22. Due to the general insignificance of the results obtained for ethanol concentration, this study assumes a negligible ethanol emission from the barns regardless of the management technique employed.

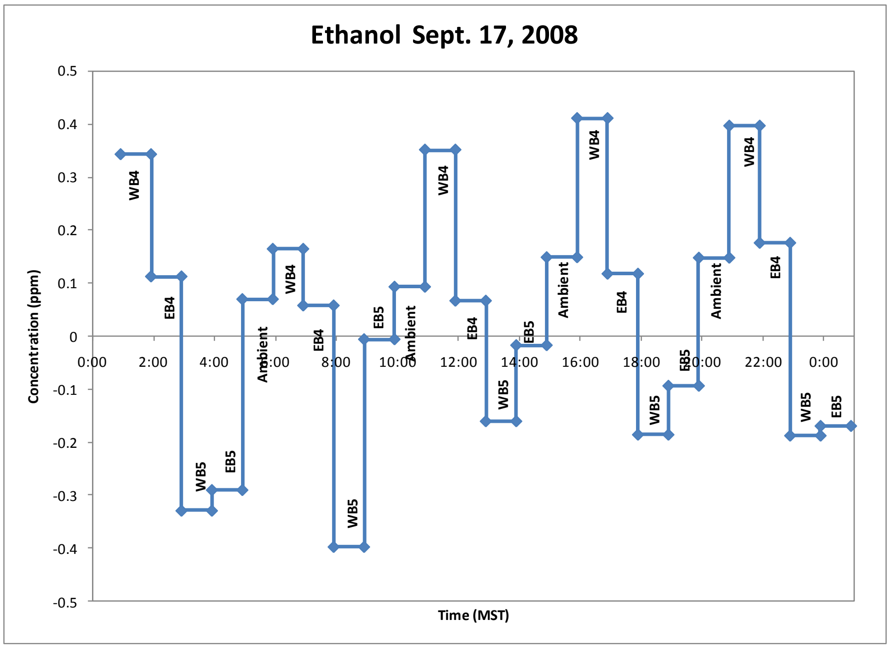

Figure 22. Average daily concentration for Ethanol.

Similar to the behavior of NH_3 concentration in the barns, the Nitrous oxide (N_2O) concentration in the high-rise building shows a higher degree of variability than the concentration observed in the manure-belt (figure 23), and the N_2O concentration from the high-rise building is consistently higher than that from the manure-belt building throughout the sampling period. This could be due to the longer duration of the manure in the high-rise building as compared to the manure-belt building. The N_2O average daily concentration for the specified monitoring period ranges from 0.386 ppm to 0.463ppm with an average of 0.427 ppm for the manure-belt building and 0.443 ppm to 1.593 ppm with an average of

1.123 ppm. No significant emissions were recorded for N_2O, which was consistently zero or close zero for both management techniques. This was hard to explain especially in the case of the high-rise building where droppings accumulate for a long time before removal, taking into account that IPCC Guidelines suggest, for solid manure-based housing systems, an emission factor equal to 2% of the N excreted by the animals (IPCC, 2000). The summary of the N_2O emission factors for both type of management technique may be found in Table 12.

The average daily carbon dioxide (CO_2) concentration shows a higher variability in both the manure-belt and high-rise buildings (figure 25) when compared to the degree of variability observed in the NH_3 concentration (figure 16), especially in the manure-belt building. Also, the concentration of CO_2 in the high-rise building was consistently higher than that observed in the manure-belt building throughout the sampling period. A mean CO_2 concentration of 880 ppm and a range of 511 ppm to 1540 ppm were recorded for the manure-belt building while the high-rise building concentration ranges from 835 ppm to 1621 ppm and a mean of 1256 ppm. The CO_2 emission rate tends to follow similar pattern with slight difference during the early days of the sampling period for both management techniques as shown in figure 26. The emission factor for the manure-belt building ranges from 61 $Ibyr^{-1}bird^{-1}$ to 109 $Ibyr^{-1}bird^{-1}$ with a mean of 84 $Ibyr^{-1}bird^{-1}$ and that of the high-rise building ranges from 61 $Ibyr^{-1}bird^{-1}$ to 94 $Ibyr^{-1}bird^{-1}$ and a mean of 84 $Ibyr^{-1}bird^{-1}$. Although the population of the birds in both houses slightly differs (manure-belt; 53,800 birds and high-rise; 118,700 birds) but this does not reflect in their CO_2 emission rate. This could be

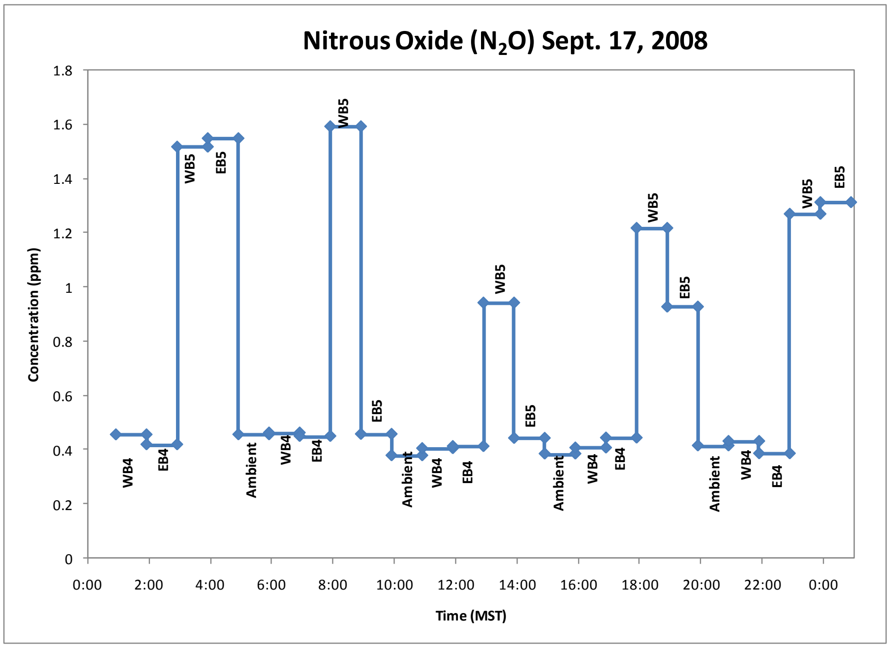

Figure 23. Average daily concentration for Nitrous Oxide

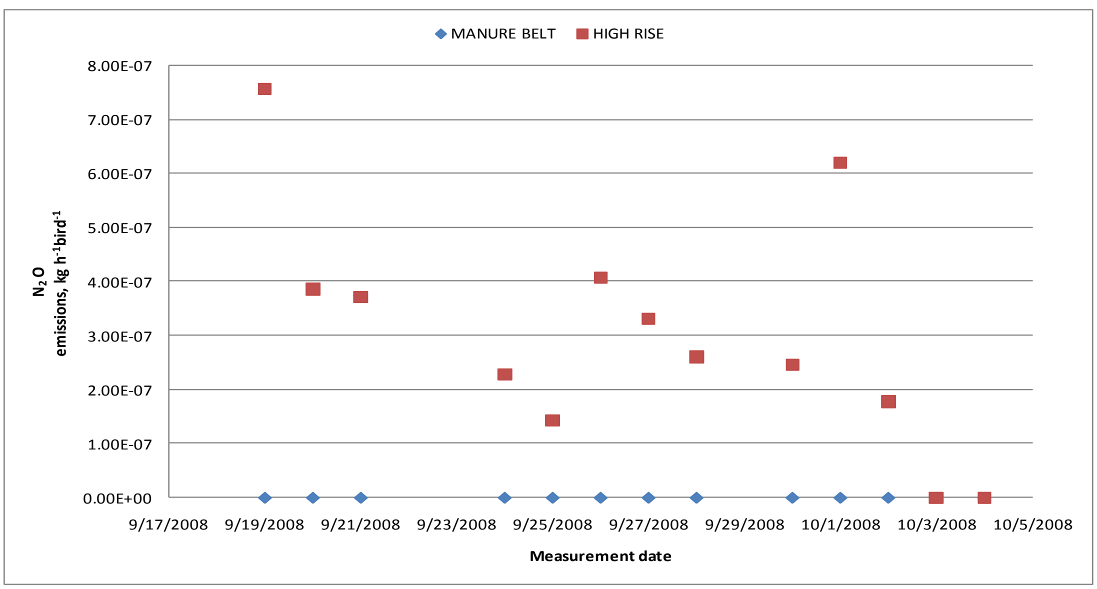

Figure 24. Daily average Nitrous Oxide emission from the two different management techniques.

due to the higher ventilation rate experienced in the high-rise building compared to the manure-barn building.

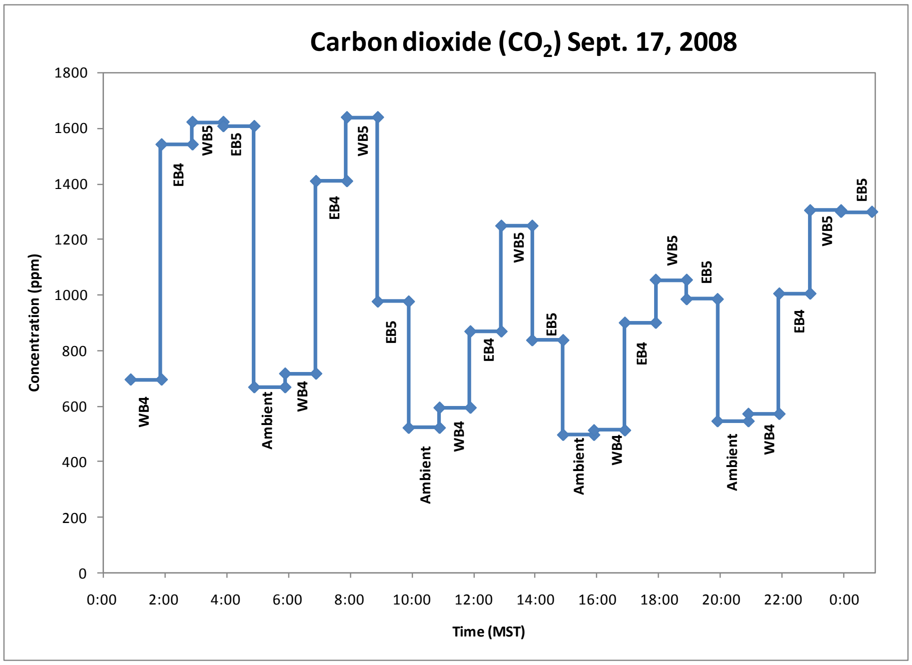

Figure 25. Average daily concentration for Carbon dioxide

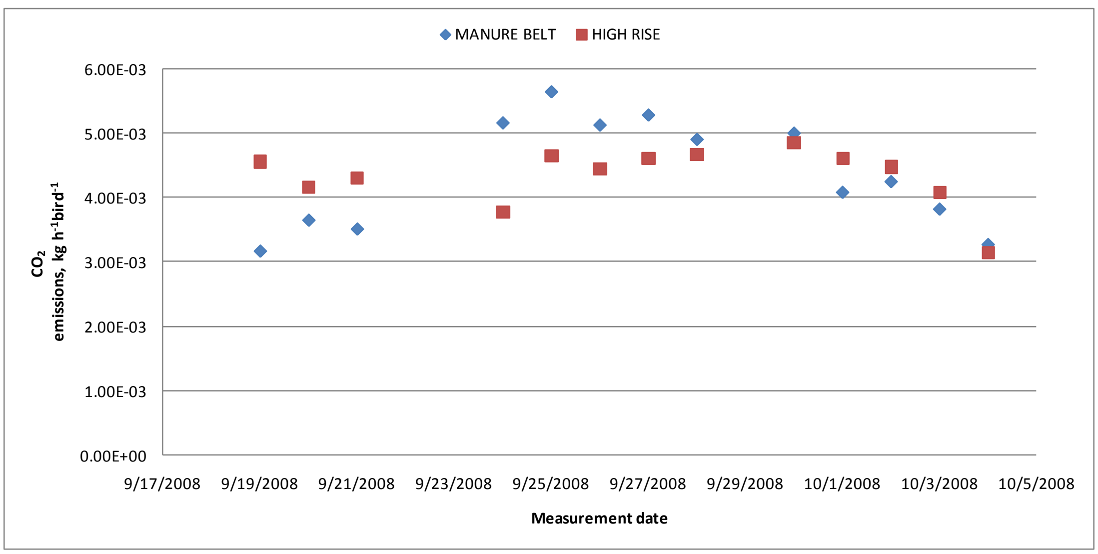

Figure 26. Daily average Carbon-dioxide emission from the two different management techniques

Table 12. Summary of the average ventilation rates and average emission factors for NH_3, N_2O and CO_2 gases over the sampling period of 13 days.

		Manure-Belt building				High-Rise building			
		Mean	Minimum	Maximum	SD	Mean	Minimum	Maximum	SD
Ventilation rate	$m^3h^{-1}bird^{-1}$	2.74	2.11	3.02	0.26	2.09	1.40	2.34	0.27
	$m^3h^{-1}AU^{-1}$	295	227	325	28	495	333	554	65
Gaseous Emissions									
Ammonia (NH_3)	$kghr^{-1}bird^{-1}$	1.44E-06	2.94E-07	4.64E-06	1.09E-06	1.14E-05	4.62E-06	1.44E-05	2.65E-06
	$lbyr^{-1}bird^{-1}$	0.03	0.01	0.09	0.02	0.22	0.09	0.28	0.05
Nitrous Oxide (N_2O)	$kghr^{-1}bird^{-1}$	0	0	0	0	3.02E-07	0	7.58E-07	2.17E-07
	$lbyr^{-1}bird^{-1}$	0	0	0	0	0.01	0	0.01	0.004
Carbondioxide (CO_2)	$kghr^{-1}bird^{-1}$	4.37E-03	3.16E-03	5.65E-03	8.51E-04	4.33E-03	3.14E-03	4.85E-03	4.60E-04
	$lbyr^{-1}bird^{-1}$	84.47	61.10	109.06	16.45	83.59	60.68	93.63	8.88

Note: 1 AU = 500kg

Particulate matter

SUMMARY AND CONCLUSIONS

ENGINEERING SIGNIFICANCE

PROPOSED FUTURE WORK

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