UDAQ NAEMS:
Cache Valley Poultry Facility Emissions

Final Report

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EXECUTIVE SUMMARY

Large confined animal feeding operations (CAFOs) and other agricultural activities have the potential to affect air quality through direct emissions of gases and aerosols such as ammonia, hydrogen sulfide, particulate matter (PM), volatile organic compounds (VOCs), hazardous air pollutants, microorganisms, and odor. Furthermore, many of the emitted gases may also photochemically react with themselves or other air-borne compounds to form additional gaseous or solid-phase pollutants (e.g. ammonium sulfate or ammonium nitrate based $PM_{2.5}$). The National Air Emission Monitoring Study (NAEMS) project was funded by the Agricultural Air Research Council (AARC) to evaluate air pollutant emissions from a variety of agricultural sources nationwide. Under the work described in this document, Utah State University (USU) conducted a similar study on agricultural emissions at a poultry facility in Northern Utah wherein two separate buildings under differing manure management scenarios (high-rise vs. manure-belt) were examined. The study was divided into two broad approaches: (1) direct, real-time measurement of building ventilation and inlet and exhaust pollutant parameters for the derivation of system emission rates and (2) in-building grab sampling and subsequent analysis of total nitrogen in the feed, products, and waste to determine potential ammonia (NH_3) and amine gas-phase emissions by total system nitrogen mass balance.

The real-time sampling system observed average temperatures and relative humidities inside the high-rise barn (Building 5) of 20.3°C ± 4.2°C and 46.1% ± 7.6%, respectively, while the same parameters in the manure-belt barn (Building 4) averaged 19.3°C ± 5.2°C and 46.9% ± 7.5%, respectively. The ventilation rates between the two buildings were rather similar, ranging from 0.80 m^3 hr^{-1} $bird^{-1}$ to 4.80 m^3 hr^{-1} $bird^{-1}$, with a mean of 2.02 m^3 hr^{-1} $bird^{-1}$ for the high-rise barn, while the ventilation rates ranged from 0.80 m^3 hr^{-1} $bird^{-1}$ to 6.00 m^3 hr^{-1} $bird^{-1}$, with a mean of 2.20 m^3 hr^{-1} $bird^{-1}$ for the manure-belt barn.

Average NH_3 emissions were measured to be 72 ± 17 g day^{-1} AU^{-1} for the high-rise system and 9.1 ± 7 g day^{-1} AU^{-1} for the manure-belt system (Note: one AU is equal to 500 kg live animal weight). The ammonia emission reduction factor for the manure-belt system compared to the high-rise system was 87%. However, it must be kept in mind that this does not account for ammonia emissions for the manure storage barn, which in reality is part of the manure-belt system. It should also be noted that ambient (external to the test barns) values of NH_3 were consistently less than or equal to 1 ppm. No significant emissions were observed for nitrous oxide (N_2O), hydrogen sulfide (H_2S), and ethanol (C_2H_5OH or EtOH), which were typically measured below or very near the instrumental lower limits of detection. Carbon dioxide (CO_2) emissions were also monitored, and it was found that while the base emissions differed very little between the two barns, when normalized by buildings' bird populations, the CO_2 emissions came out essentially the same for the two waste management scenarios. The high-rise barn has CO_2 emissions of 104 ± 11 g day^{-1} AU^{-1} and the manure-belt barn showed CO_2 emissions of 105 ± 20 g day^{-1} AU^{-1}.

As with the CO_2 emissions, the base particulate emissions showed a difference between the two management schemes: the average manure-belt building $PM_{2.5}$, PM_{10}, and TSP emission rates were 33 ± 17 g min^{-1}, 821 ± 316 g min^{-1}, and 1,691 ± 775 g min^{-1}, respectively, and 28.4 ± 10 g min^{-1}, 382 ± 286 g min^{-1}, and 997 ± 462 g min^{-1} for the high-rise building, respectively. However, when normalized by buildings' bird populations, the difference in all PM emissions became insignificant at one standard deviation. These emission rates on a per animal unit (AU) basis for $PM_{2.5}$, PM_{10}, and TSP emissions are 0.11 ± 0.06 kg day^{-1} AU^{-1}, 2.78 ± 1.03 kg day^{-1} AU^{-1}, and 5.52 ± 2.53 kg day^{-1} AU^{-1}, respectively, for the manure-belt barn and 0.21 ± 0.07 kg day^{-1} AU^{-1}, 2.80 ± 2.10 kg day^{-1} AU^{-1}, and 7.32 ± 3.39 kg day^{-1} AU^{-1} for the high-rise barn, respectively.

As part of the parallel portion of this study, samples of animal feed, eggs and animal waste were collected weekly from three barns (manure barn, Building 4 - manure-belt, and Building 5 - high-rise) from May 2008 to November 2009. These samples were analyzed to determine ammonia content, total Kjeldahl nitrogen content and ammonia emission. The yearly average calculated NH_3 values for manure barn, Building 4 and Building 5 were determined in units of mg NH_3 g_{manure}^{-1} as 1.1 ± 0.2, 0.6 ± 0.1, and 0.8 ± 0.1, respectively. The yearly average calculated TKN values, in units of percent total nitrogen, were determined as 2.0% ± 0.3, 1.6% ± 0.3 and 1.9% ± 0.3 for manure barn, Building 4 and Building 5, respectively. The yearly average of NH_3 emission using this methodology was determined to be 440 ± 180 mg NH_3 $bird^{-1}$ day^{-1} for Building 4 (manure barn), and 540 ± 190 mg NH_3 $bird^{-1}$ day^{-1} for Building 5 (high-rise). For comparisons with the values obtained through the real-time measurements, these are equivalent to 116 ± 47.4 g NH_3 AU^{-1} day^{-1} for Building 4 (manure barn), and 142 ± 50.0 g NH_3 AU^{-1} day^{-1} for Building 5 (high-rise).

The ammonia and organic amines emissions in exhaust air at the examined confined poultry facility were measured by using a sulfuric acid trapping solution in an impinger train followed by ion chromatography (IC) detection. The yearly average concentrations of ammonia in exhaust air at the barns were calculated at 11.9 ± 2.9 ppm at the manure-belt barn (Building 4) and 12.7 ± 3.1 ppm at the high-rise barn (Building 5). No organic amines were detected in the collected ambient air samples by the ion chromatography method. As there were no amines detected by the IC method, limits of detection of organic amines in air were studied. The results showed that the organic amines in the manure must occur at a minimum concentration of 1 ppm in order to have sufficient vapor pressure so that enough is transported to the impingers for trapping and subsequently be detected by the IC.

INTRODUCTION

This report summarizes the work conducted, the results available, and the products produced for the Utah Division of Air Quality's (UDAQ) and the U.S. Department of Agriculture's (USDA) National Resources Conservation Service's (NRCS) project to assess air pollutant emissions from a confined animal feeding operation (CAFO), specifically a layer poultry operation under differing manure management systems (high-rise vs. manure-belt). Measurements began in the summer of 2008 and continued through the fall of 2009. Results from this work have been compiled into two Utah State University (USU) Master of Science theses: one through the Department of Civil and Environmental Engineering (Olumuyima O. Ogunlaja, *Measurement of Air Pollution Emissions from a Confined Poultry Facility*, 2009) and one through the Department of Chemistry and Biochemistry (Hanh Hong Thi Dinh, *Analysis of Ammonia and Volatile Organic Amine Emissions in a Confined Poultry Facility*, 2010).

It must be noted that the overall project was beleaguered with numerous difficulties and delays, but key among these were several personnel changes and challenges throughout the project lifetime. Over the course of the project, several student workers, both undergraduate and graduate, left the University and/or project prematurely or completely, which greatly complicated the planned experiments. However, the most crippling loss was the resignation of the Co-Investigator, Dr. Philip Silva from USU's Department of Chemistry and Biochemistry (CAB). Dr. Silva left Utah State University early in 2009 and relocated to USDA-ARS's facility in Bowling Green, Kentucky. However, Dr. Robert Brown, also from USU/CAB, stepped in and served as the main advisor for the Chemistry M.S. Graduate Student, Ms. Dinh, although Dr. Silva remained externally attached to the thesis process.

PROJECT TASKS (as per NRCS quarterly form)

As per the original guidelines, eight tasks were outlined under the project. These tasks were as follows: (1) establish a library of existing air emission studies for animal feeding operations, (2) identify representative locations to monitor activities, (3) develop an air emissions monitoring plan, (4) purchase, set-up, calibration, and field test equipment, (5) perform air monitoring study, (6) evaluate results of monitoring, (7) develop information to support a plan to assist producers in meeting project related environmental requirements, (8) keep records and report accomplishments.

BACKGROUND AND PREVIOUS EMISSION STUDIES

Livestock and poultry are raised on an estimated 1.3 million farms throughout the nation. About 238,000 of these farms are considered animal feeding operations (AFO): agriculture enterprises where animals are kept and raised in confinement (Claudia, 2006). Confined Animal Feeding Operations (CAFOs) are AFOs that meet certain EPA criteria. CAFOs make up approximately 15 percent of total AFOs. In addition to its significant contribution to the nation's economy, livestock agriculture also contributes significantly to the U.S. job market.

Between 1982 and 1997, the number of animal feeding operations in the United States decreased by 51 percent, while livestock production increased by 10 percent. In some areas, even greater changes in concentration have occurred (National Research Council, 2003). During the past few decades, the increasing concentration of food production (meat, eggs, milk, etc.) from animals in very large feeding operations has focused public attention on the associated environmental issues (National Research Council, 2003). Previously, public policy concerns were typically focused on the impacts of these large operations on available water resources. If animal wastes are not managed properly, they can adversely impact water quality through surface runoff and erosion, direct discharges to surface waters, and leaching into soil and groundwater (Claudia, 2006). Recently, however, more attention has been focused on the effects of air emissions. Animal feeding operations (AFO) can also affect air quality through direct emissions of gases and aerosols such as ammonia, hydrogen sulfide, particulate matter (PM), volatile organic compounds (VOCs), hazardous air pollutants, microorganisms, and odor. These gases may also photochemically react with themselves or other air-borne compounds to form additional gaseous or solid-phase pollutants (e.g. ammonium sulfate or ammonium nitrate based $PM_{2.5}$).

In addition, AFOs also produce gases such as carbon dioxide and methane that have been associated with climate change (Jeff and Holly, 2009). The generation rates of odor, manure, gases, particulates, and other constituents vary with weather, time, animal species, housing type, feed type, and differing manure management system used for storage and handling (National Research Council, 2003; Claudia, 2006). Within the various livestock facilities, emission sources include barns, feedlot surfaces, and manure storage areas. The bulk of air emissions often come from the microbial breakdown of manure stored in pits or lagoons and spread on fields, although simple animal activity can also produce significant emissions (especially PM). Each emission source will have a different profile of substances emitted, with rates that fluctuate throughout the day and the year. Pollutants associated with AFOs have a number of environmental and human health impacts; most regulatory concerns are focused on possible health effects.

Recognizing the growing importance of the potential contributions of CAFOs and other agricultural sectors to local, regional, and even global air quality, a collaborative workshop organized by the USDA's Cooperative State Research, Education, and Extension Service (CSREES), NRI Air Quality Program was held in Potomac, Maryland (USA) in early June 2006. The workshop (*Workshop on Agricultural Air Quality: State of the Science*, 2006) brought together national and international scientists who presented over 300 platform presentations and posters on most current agriculturally related air quality measurement techniques, emission rates, and modeling techniques. The proceedings of the workshop were compiled into a 1300-page document that serves as the single most up-to-date document regarding agricultural air pollutant emissions. An electronic version of this compilation is included in the appendix of this document (Aneja et al., 2006).

Similarly, in September 2009, the *Journal of the Air & Waste Management Association* (JAWMA) published a special issue, Agricultural Air Quality: State of the Science (Aneja, 2009). This special issue, available on-line or hardcopy to AWMA members, contains 13 updated and peer-reviewed versions of presentations from the workshop. Other peer-reviewed manuscripts from the workshop have also appeared in separate issues of JAWMA and other relevant journals, such as *Atmospheric Environment*, the *Journal of Environmental Quality*, and the *Journal of Atmospheric Chemistry*.

National Air Emission Monitoring Study (NAEMS)

As indicated above, the currently available scientific data related to livestock air emissions that are needed to properly regulate AFOs under such federal regulations as the Clean Air Act (CAA), CERCLA, and EPCRA are limited. In order to address the lack of scientific data, the National Air Emission Monitoring Study (NAEMS) was established in 2006 by a voluntary Air Compliance Agreement between the EPA and the pork, dairy, egg, and broiler industries. Livestock producers have also provided support for the NAEMS project. The objectives of the NAEMS program are to accurately assess emissions from livestock operations and other CAFOS and compile a database for estimation of emission rates, and to promote a national consensus for emissions-estimation methods/procedures from animal feeding operations.

The National Air Emission Monitoring Study (NAEMS) project has been funded by the Agricultural Air Research Council (AARC) to evaluate agricultural emissions nationwide beginning in 2006. The NAEMS is overseen by the EPA Office of Air Quality Planning and Standards (OAQPS), and the project is managed by Purdue University. The project is designed to develop methods to quantify air emissions from the U.S. confined animal feeding operations and to perform air monitoring at various poultry, dairy and swine operations to measure emissions from these operations. Results from these studies are aimed at evaluating different management practices to determine if they are effective at reducing agriculturally derived air emissions.

Literature Review (Emission Rates)

Emission rate refers to the rate at which gases or particulates are released into ambient air. These rates may also be expressed as a mass flux per unit area and time from a particular surface (e.g. g m^{-2} day^{-1}) or normalized by another parameter such as animal count or animal mass (e.g. g $bird^{-1}$ day^{-1}). In reference to agricultural emissions, rates are often normalized to the number and weight of animals in terms of animal units (AU), where one AU is equal to 500 kg of animal live weight. 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 may lead to misleading interpretations. Also, referenced data collection periods vary widely, ranging from a few hours to several days. The following summary tables compile relevant agriculturally related air pollutant emissions; where possible, comparative units have been derived.

Ammonia

Gas-phase ammonia (NH_3) is the predominant pollutant gas in poultry production and most other CAFO facilities. 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). The majority of NH_3 emissions from animals originate from droppings, a mixture of fecal matter and urine, which in the case of poultry production is considered a single waste product. The chemistry of gas-phase NH_3 formation is discussed elsewhere (Elzing and Monteny, 1997; Groot Koerkamp et al., 1998a; Arogo et al., 2006).

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. 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).

Various attempts have been made to quantify NH_3 emissions from livestock production facilities (Burns et al., 2003; Groot Koerkamp et al., 1998a; Hinz and Linke, 1998; Patni and Jackson, 1996; Wathes et al., 1997; Maghirang and Manbeck, 1993). However, currently there are limited data regarding ammonia emission rates from U.S. commercial layer houses. A recent inventory from UK agriculture estimated ammonia 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. 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.

Table 1. Ammonia emission factors from poultry housing in the UK

Production unit	**Notes**	**Emission Factor g NH_3 day^{-1} AU^{-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. (2000)

Even though ammonia emissions from various European production facilities have been quantified (Groot Koerkamp et al., 1998b; Hinz and Linke, 1998; Wathes et al., 1997), those results 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: 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. (1998a) reported the ammonia emission rates found in Table 2. Four facilities per housing type in each country were sampled for a 24-hour period under both summer and winter conditions. 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 and the test conditions may have 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.(1998a)

	Emission Rate (g day^{-1} AU^{-1})			
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 ≥ 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 or buildings 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
(unless noted, the uncertainty represents ±1 standard deviation)

State	Facility type	Barn 1 Emission rate (g day^{-1} AU^{-1})	Barn 2 Emission rate (g day^{-1} AU^{-1})
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 for 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 (g day^{-1} AU^{-1})	**Range (g day^{-1} AU^{-1})**
Poultry					
broiler	Litter	Delmarva Peninsula	Summer	716	182 – 1450
broiler	Litter	Arkansas	Oct. – April	88.2	
layer	Cage/high-rise	Iowa	Jan. – Dec.	262	204 – 295
layer	Cage/belt	Ohio	Mar. – July	303	
layer	Cage/deep pit	Ohio	Mar. – July	482	

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

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. NH_3 emission rates ranged from 1,426 to 50,520 g day^{-1} $barn^{-1}$ in summer and 912 to 45,432 g day^{-1} $barn^{-1}$ in winter. 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 5 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 U.S.

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

Location	**Emission Rate ($g\ day^{-1}\ AU^{-1}$)**	**Emission Rate ($g\ day^{-1}\ bird^{-1}$**)**
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. (1998a), presented previously

** Assuming an average weight of 2 lb $broiler^{-1}$ (U.S. EPA, 2004), there are about 552 broilers per 500 kg live animal weight (1 AU).

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 according to NH_3 concentration range. Sample periods were 48 hours or more in length. 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 $0.90 \pm 0.037\ g\ day^{-1}\ bird^{-1}$ ($306 \pm 16\ g\ day^{-1}\ AU^{-1}$) in IA and $0.83 \pm 0.099\ g\ day^{-1}\ bird^{-1}$ ($275 \pm 36\ g\ day^{-1}\ AU^{-1}$) in PA; manure-belt house rates averaged $0.054 \pm 0.0048\ g\ day^{-1}\ bird^{-1}$ ($17.6 \pm 1.5\ g\ day^{-1}\ AU^{-1}$) for daily manure removal and $0.094 \pm 0.019\ g\ day^{-1}\ bird^{-1}$ ($30.8 \pm 5.9\ g\ day^{-1}\ AU^{-1}$) 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.

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

Country	House Type	Season	Manure Removal Interval	Emission Rate (g day^{-1} AU^{-1})
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^{-1} yr^{-1} 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 to 63 days, depending on the facility, yielding emission data on 5 to 6 flocks per facility. Interestingly, the investigators found seasonal trends in exhaust NH_3 concentration and ventilation rates, but not in overall 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 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 g day^{-1} AU^{-1} for the first 14 days (plus or minus one standard deviation). After 14 days, the average emission rate across all flocks was 225 ± 50 g day^{-1} AU^{-1}. 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, which typically differ from those employed in the United States: (1) litter was usually changed between each flock, and (2) birds were slaughtered at a lower weight.

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 day^{-1} bird^{-1})	**(g day^{-1} AU^{-1})[#]**		
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^{-1} (U.S. EPA, 2004)
? not explicitly stated, but inferred from data, statements in article, or common practice
N/A = not available

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. The first study, which was reported by Siefert et al. (2004), involved a side-wall ventilated house and yielded emission rates with a mean of 1.18 g day^{-1} bird^{-1} and a range of 0.27 – 2.17 g day^{-1} bird^{-1}. 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 day^{-1} bird^{-1}, approximately one-tenth of that found in the Siefert et al. (2004) study. 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 may dry 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.

In review, the ranges of poultry ammonia emissions rates are summarized in Table 8 with emission rates reported for Europe and the United States separated for comparison. There exists a large variation in emission rates found in literature, even for those utilizing the same housing/manure management techniques. This suggests that there are likely 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 the U.S. and Europe, the emission rates reported in Europe tend to be smaller in both range and magnitude; the maximum reported emission rates for Europe are under 300 g day^{-1} AU^{-1}, while maximum emission rates in the U.S. are between 300 and 1450 g day^{-1} AU^{-1}.

Table 8. Ranges of poultry NH_3 emission rates from the above referenced literature

Species	**Housing/Manure Management**	**Emission Rate Ranges (**g day^{-1} AU^{-1}**)**	
		United States	**Europe**
Poultry	Broilers on litter	88.2 – 1450	45.6 – 199
	Layers in high-rise	86.3 – 523	14.4 – 224
	Layers in deep-pit	86.3 – 482	177 – 290
	Layers with manure-belt	17.5 – 307	14 – 96
	Turkeys on litter	6.1 – 296	

Nitrous Oxide

Nitrous oxide (N_2O) 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 and Pitts, 2000). 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 depending on the aerobic or anaerobic state of the system. 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 may also indirectly influence the production of N_2O.

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 day^{-1} AU^{-1}. The lowest emissions values were from swine housing and the highest were from poultry housing.

Amines Compounds

Gas-phase amine emissions have been studied by various researchers to establish their inherent toxicity and the potential carcinogenicity of their reaction products (Akyuz, 2007). Aliphatic amines such as methylamine, dimethylamine, ethylamine, diethylamine, etc., are known to be important in air pollutants due to their odorous and toxic characteristics (Akyuz, 2007). It is also well known that they can react with nitrite, nitrate, NO_x or OH radicals in the environment and can form toxic carcinogenic N-nitrosamines (Skarping and Bellander, 1986; Santagati et al., 2002). Additionally, most alkylamines are irritants to the skin, mucous membranes, and respiratory tract. Monitoring of the levels of aliphatic amines in ambient air is important to prevent human exposure to these compounds through inhalation and to minimize any health associated problems.

Currently, environmental concentrations of aliphatic amines are not well known. To date, only a few studies of atmospheric aliphatic amines have been reported, mostly near areas suspected of having strong emission sources. Michael et al. (2007) measured concentrations of triethylamine and trimethylamine in urban air at 16.5 $\mu g\ m^{-3}$ and 1.2 $\mu g\ m^{-3}$, respectively. In another study, Schiffman et al. (2001) analyzed the volatile organic compounds (VOCs) in the air and lagoon water at swine operations in North Carolina. The results from the samples contained some amine compounds including methylamine, ethylamine and trimethylamine and their concentrations were reported as 18.6 $\mu g\ m^{-3}$, 324 $\mu g\ m^{-3}$, and 2.4 $\mu g\ m^{-3}$, respectively. Table 9 shows a summary of previous studies of amines in animal agriculture.

Table 9. Amines studies in animal agriculture

Compound	Facility type	Concentration (ppb)	References
Methylamine	swine	18	Schiffman et al., 2001
Methylamine	swine	24	Devos et al., 1990
Ethylamine	swine	324	Schiffman et al., 2001
Ethylamine	swine	603	Devos et al., 1990
Trimethylamine	swine	2.4	Schiffman et al., 2001
Triethylamine	swine	309	Schiffman et al., 2001
Tributylamine	dairy	5.25	Filipy et al., 2006
Trimethylamine	dairy	2.4	Filipy et al., 2006

Hydrogen Sulfide

Hydrogen sulfide (H_2S) may be 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 H_2S 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 CAFOs 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 concentration measurements 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. (2005) 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. Limited data exists on the emissions of hydrogen sulfide from livestock and poultry facilities. Most of the recent studies documenting these emissions have been conducted at the University of Minnesota and Purdue University. Emission values reported in literature are given in Table 10. These values were converted to common units as indicated in Wood et al. (2001).

Table 10. Agricultural hydrogen sulfide emissions

Housing	H_2S	Unit	Source
Broiler, litter	1	mg hr^{-1} m^{-2}	Wood et al., 2001
Swine finish, Slat	50	mg hr^{-1} m^{-2}	Wood et al., 2001
"	7-97	mg hr^{-1} m^{-2}	Ni et al., 1998
"	1-30	mg hr^{-1} m^{-2}	Heber et al., 1997
Dairy, freestall	3.6	mg hr^{-1} m^{-2}	Wood et al., 2001

Particulate Matter

Large animal production facilities may emit quantities of particulate matter (PM) that approach the limits by the CAA for industrial sources. Confined animal buildings reduce the cost of production, but are usually the most significant source of PM emissions at intensive livestock production facilities. Factors affecting building PM emissions include building design and management, animal activity, feed type, condition and handling, ventilation, and the manure collection system. Bird activity is a major cause of PM emitted by modern high-rise laying houses with stacked cages (Heber et al., 2005).

Particulates in and around poultry production sites include soil particles, bits of feed, hair or feathers, dried feces, bacteria, fungi, and endotoxins (Anderson et al., 2003). 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 particulate in animal housing (Curtis et al., 1975, Heber and Stroik, 1988, Heber et al., 1988). Soil particles from open unpaved feedlots also contribute to dust levels. PM 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 particulate levels; solid floors have much higher levels than open-mesh floors (Carpenter and Fryer, 1990, Dawson, 1990). The latter allows feces and soiled bedding to fall below the floor level and minimize particulate generated by animal activities.

There is little, but growing, research on particulate emission factors from animal agriculture facilities and their environmental impact. Most studies have focused on particulate 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. Table 11 shows the PM concentrations with different kinds of poultry and housing systems in literature.

Table 11. PM concentrations with different kinds of poultry and housing systems

Category	**Poultry Management**	**PM Concentration ($mg\ m^{-3}$)**		**Reference***
		Inhalable	Respirable	
Broilers	Floor, litter	8.2-9	1.4-1.9	Ellen et al., 2000
Broilers	Floor, day† night†	7.18 7.06		Takai et al., 1998
Laying hens	Perchery,day† night†	7.33 2.82		Takai et al., 1998
Laying hens	Cage, day† night†	1.51 0.86		Takai et al., 1998
All poultry categories together (mean)		2.22-4.58	0.19-0.64	Takai et al., 1998
All poultry categories		0.02-81.33	0.01-7.73	Donham et al., 2000
Broilers	Floor, litter		1.8-6.5	Drost et al., 2005
Turkeys	Floor, litter		< 6	Hinz et al., 1999
Laying hens	Aviaries	2.4-12		von Wachenfelt, 1999
Laying hens	Aviaries	7.6		von Wachenfelt, 1999

* All the references are in the congress proceedings of the International Symposium on "Dust Control in Animal Production Facilities".
† Day: 6:00-18:00; Night: 18:00-6:00.

Wathes et al. (1997) measured particulate emissions from a broiler and a layer facility in the U.K. (see Table 12).

Table 12. Emission of PM by poultry houses (Wathes et al., 1997)

Type	**Season**	**Inhalable PM ($g\ AU^{-1}\ hr^{-1}$)**	**Respirable PM ($g\ AU^{-1}\ hr^{-1}$)**
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 µm) PM emissions from various poultry facilities in four European countries (Table 13). Emissions were estimated from mean daily PM concentrations near air outlets and the daily mean ventilation rate through the buildings.

Table 13. Mean inhalable and respirable PM emission factors from English, Dutch, Danish, and German poultry buildings (Takai et al., 1998)

	Mean inhalable PM ($g\ AU^{-1}\ hr^{-1}$)	**Mean respirable PM ($g\ AU^{-1}\ hr^{-1}$)**
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 PM emissions (Takai et al., 1998), although this could be an artifact of measurement system bias. There were significant seasonal effects on inhalable PM emissions from both swine and poultry housing. In the same document, inhalable PM emissions from cattle buildings were not affected by season. 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 PM emissions from animal buildings in the United States.

SELECTED FACILITY DESCRIPTION

The facility selected through discussions with the UDAQ, NRCS, the Utah Farm Bureau (represented by Dr. Howard Thomas), and local producers was a commercial layer farm in northern Utah. At the initiation of the project, the farm consisted of 11 bird houses/buildings. No other livestock were present on the premises. In order to observe emissions in differing waste management scenarios, two adjacent houses of the 11 buildings were selected for use within this study: one high-rise system (Building 5) and one manure-belt system (Building 4). Figure 1 shows an annotated GoogleEarth™ photograph of the selected facility. As can be seen, the buildings were orientated in an east/west direction and both of the tested buildings were very nearly the same in cross-sectional area, 13.5 m x 158 m. The distance between the buildings was approximately 17.5 m.

Figure 1. Poultry facility site layout (annotated GoogleEarth™, 2010).

Air flow, and thus interior temperatures, through all of the buildings were controlled through mechanical ventilation. Each of the buildings had 18 exhaust fans facing north (nine in two separate banks). The fans in the west and east banks of Building 5 were circular in cross-section, with sixteen of the fans having diameters of about 1.54 m and the middle fans in each bank having a diameter of 1.24 m (see Figure 2). The west and east fan banks of Building 4 were square in cross-section, with a length and width of 1.57 m (see Figure 3). The overall total number of fans to be monitored was 36 fans, 18 for each management technique. The ventilation systems were thermostatically controlled (the fans turn on and off automatically based on the temperature of the poultry building to maintain optimum temperature for the poultry). When ambient temperatures were in excess of the desired in-house temperature (≈20-25°C), evaporative "swamp" coolers were employed to provide additional cooling capacity.

Figure 2. High-rise building (Building 5) external exhaust fans.

Figure 3. Manure-belt building (Building 4) external exhaust fans.

The high-rise building (Building 5) used a two-story system wherein the birds are housed in offset layers on the top level of the building and the waste/manure is allowed to fall through a meshed floor to the basement level (see Figure 4). As tested, the high-rise building housed an average of 53,800 birds. The collected waste is manually removed one to two times per year depending on ultimate disposal plans. Figure 5 shows a photograph of the manure storage at the bottom level of the examined high-rise building.

Figure 4. Internal view of the high-rise system (Building 5).

Figure 5. Internal view of manure storage in the high-rise building (Building 5).

The manure-belt building uses a waste management system wherein the birds are housed in stacked mesh cages, approximately four tiers high, with a traveling conveyor belt under each tier. The belts are operated periodically and remove the waste material to a separate manure storage barn located perpendicular to the other buildings (refer to Figure 1). Figure 6 shows an internal view of the examined manure-belt building. During the testing periods Building 4 (manure-belt) held an average of 118,700 birds, greater than double the capacity of the high-rise building. Figure 7 shows the interior of the separate manure storage barn. As with the manure storage in the basement level of the high-rise building, the collected wastes within the manure barn were manually removed one to two times per year, depending on ultimate disposal plans.

Figure 6. Internal view of the manure-belt system.

Figure 7. Internal view of manure storage barn (manure-belt depository).

METHODOLOGIES

The methodologies and protocols described herein are presented in full and ample detail. However, detailed information can be found in the theses relative to his project that are included in electronic form in the appendices of this report (Ogunlaja, 2009; Dinh, 2010).

Generalized Emission Rate Determination Protocols

In general, the poultry houses were treated like a series of point sources, wherein the net emissions to the atmosphere can be determined by a simple mass balance approach. The gaseous emission or particulate 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:

$$ER = \{(C_P - C_{PBackground}) \text{ x } V_T\} / 10^6$$

where:

ER = emission rate of pollutant gas (kg h^{-1})
V_T = Total building ventilation rate (m^3 h^{-1})
C_P = concentration of the pollutant at the exhaust fan (μg m^{-3})
$C_{Pbackground}$ = background ambient pollutant measurement (μg m^{-3})

Note that the concentrations were typically measured in parts per million (ppm) but converted to a mass per volume concentration (μg m^{-3}) using the following relationship:

$$C_{\mu g/m3} = (1000 \text{ x } C_{ppm} \text{ x } MW_p) / 24.45 \qquad (RT/P) = 24.45 \text{ (at standard conditions)}$$

where:

$C_{\mu g/m3}$ = concentration of pollutant (μg m^{-3})
C_{ppm} = concentration of pollutant (ppm)
MW_p = molecular weight of pollutant
R = gas constant
T = absolute system temperature
P = absolute system pressure

The above approach is effective as long as representative pollutant measurements can be made at the inlet and outlet of each test building and the total building ventilation rates (e.g. m^3 hr^{-1}) can be effectively monitored.

Emissions via Nitrogen Mass Balance

As previously mentioned, ammonia nitrogen (NH_3-N) in livestock manure represents one of the most important sources of manure nitrogen losses to the atmosphere (Yang et al., 2000). The nitrogen content of the animal wastes varies greatly from farm to farm depending on animal diet, amount and type of bedding added, moisture added, etc. (Jokela and Meisinger, 2004). Most of the nitrogen lost from animal production systems is volatilized ammonia or, potentially, other amine-based compounds, which can be used to quantify nitrogen emissions. Emission rates are usually expressed in terms of mass of NH_3 or ammonia nitrogen (NH_3-N) per unit time and per animal (or live weight units) or per unit area (surface sources).

Measurements of individual emissions (e.g., ammonia volatilization, nitrogen runoff, and nitrate leaching) are often difficult and expensive (National Research Council, 2003). A nitrogen mass balance-based method calculates emissions, or nitrogen loss (N_{Loss}) to the environment, as the difference between all inputs (N_{input}), such as the nitrogen content of the feed, and measurable outputs (N_{output}), such as the nitrogen content of the litter, waste, and products (e.g. eggs), of the system under study. Using this technique, maximum NH_3 emissions can be estimated by performing a mass balance for nitrogen. A mass balance for nitrogen establishes an upper limit for the estimation of NH_3 emissions, after adjusting the nitrogen loss by a factor of 17/14 to account for the difference in molecular weight between atomic nitrogen and NH_3. This relationship is expressed in the following relationship:

$$N_{loss} = N_{input} - N_{output}$$

Using this approach, nitrogen concentrations of all materials, including animal flesh or other products such as milk and/or eggs, entering and leaving the target housing facility must be determined or estimated. Feed, fresh bedding, manure, milk, and eggs can be chemically analyzed for total nitrogen. Data regarding feed consumption quantities and amount/type of bedding must also be obtained from the producers. In this study, the total nitrogen content of animal products and waste, as well as their ammonia content, were determined using total Kjeldahl titration method, and a total nitrogen balance (in-take vs. out-take) was calculated.

Bird Count

Ultimately, the emission rates were to be normalized by the number of birds in each building. These data were obtained weekly directly from the producer. For example, from May 31, 2008 through April 25, 2009, the average counts for Building 5 (high-rise) and Building 4 (manure barn) were 51,614 ± 2,273 and 116,040 ± 1,199 birds, respectively. The uncertainty represented one standard deviation. However, it should be noted that over the duration of the study, in general, the bird counts in each building consistently dropped by around 0.2% per week due to mortality and culls.

Overall Sampling Network

Figure 8 shows the schematic diagram of the monitoring site specifying the approximate location of sampling points and relevant house dimensions. The MAEMU (mobile air emission monitoring unit) is a custom built trailer which houses most of the pollutant measurement and data acquisition instrumentation. Gaseous samples were transferred to the MAEMU via 3/8" (O.D.) Teflon sampling lines which collected air samples from the negative pressure side of each fan bank. At each fan bank, the Teflon (TFE) sample lines were branched into four separate inlets, each with its own 47 mm (dia.) TFE particulate filter. The filters were inspected bimonthly and replaced as need. Additionally, a separate sample line was exposed directly to the ambient air, as near as practicable to the building inlets, to determine "background" pollutant concentrations.

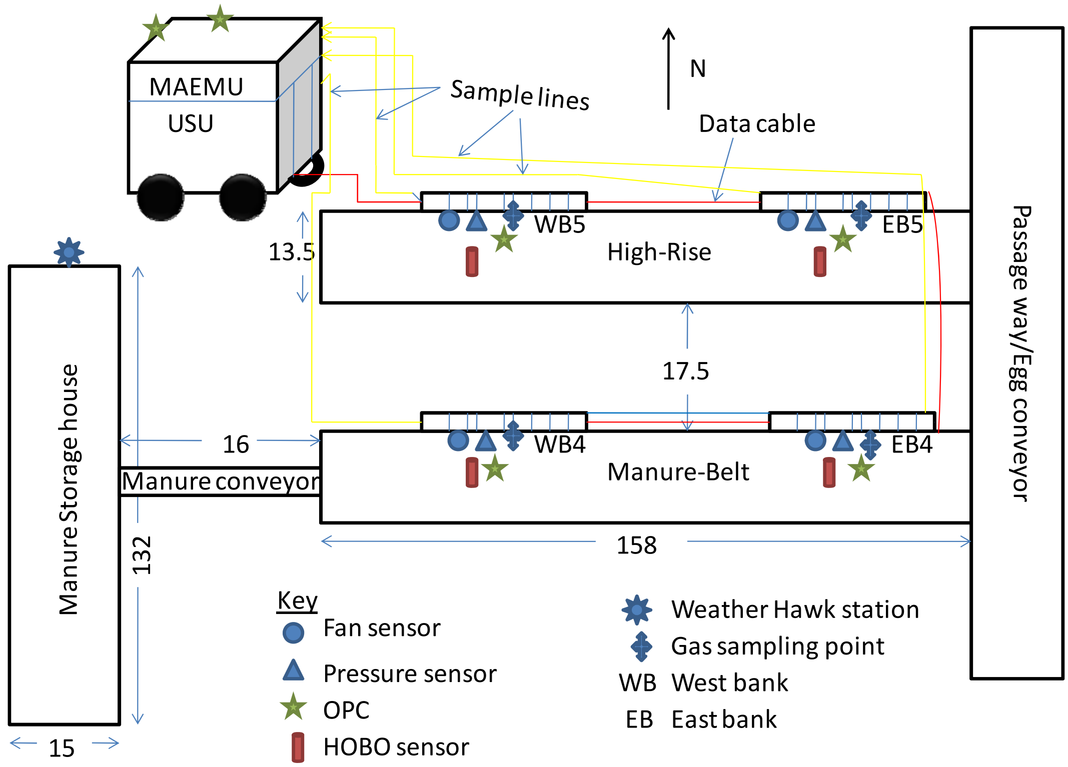

Figure 8. Schematic layout of the sampling site and instrument locations (dimension are in meters).

Small, individual vacuum pumps were used to pull sample air through each TFE tube into the MAEMU and to the subsequent analytical instruments. A series of custom-built, solenoid-actuated, computer-controlled valves (see Figure 9) were used to automatically switch between the five sample locations at one-hour intervals. The lines that were not actively being monitored were continually vented through an exhaust port so that, when the valves switched, lost samples could be kept to a minimum. The ambient air (background) line was sampled first, followed in order by the west fan bank of Building 5 (high-rise), the east fan bank of Building 5, the west fan bank of Building 4 (manure-belt), and the east fan bank of Building 4. In effect, this meant each point within the system was sampled four to five times per day, with a rolling 1-hour shift in the sample times as the days progressed.

Figure 9. Custom-built gas sampling valving system.

Barn Ventilation Rates

The ventilation rates at each barn were continuously monitored by recording the number of active fans and their rotation speed using induction sensors placed on every ventilation fan in the buildings and correlating their fan speed values (RPM) with an airflow rate by calibrating each fan using a hand-held propeller anemometer (Dwyer VT 140 thermo-anemometer). Figure 10 shows the typical location of the induction sensor relative to the fan motor. The sensor counted the number of times the fan spoke passed in front of it, and this value was automatically recorded as a summation every 10 minutes. The recorded counts were then converted to velocity (RPM) by dividing the count by the number of spokes on the fan wheel and the averaging period (10 minutes).

The velocities, in RPM, were then converted to an air flow rate in $ft^3\ min^{-1}$ (or $m^3\ min^{-1}$) by employing an individual fan calibration equation for each of the 36 fans. The calibration relationships were developed by repeatedly measuring at the fan's shroud face velocity following spacing recommended by the U.S. EPA, Method 1 for stack sampling (U.S. EPA, 1976). The method stipulates the spacing of traverse points via use of the shroud's diameter for the circular shroud and area for the rectangular shroud. The locations of the 16 traverse points were nominally designed to represent the centroid of equal areas for the two types of fan shrouds shown in Figures 11 and 12. Table 14 shows the specific traverse points for fans in poultry Building 5 (high-rise). The traverse points for Building 4 (manure-belt) were simply derived from an equal-spaced 4X4 grid, as indicated in Figure 12. The flow rate for each fan was calculated as the product of the average face velocity and the individual fan's cross-sectional face area ($Q = V_{avg} \times A$). Linear relationships were subsequently developed for each fan relating RPM (independent variable) to fan flow rate (dependent variable). The individual fan calibration graphs and equations can be found in Appendix A of O. Ogunlaja's thesis (2009), which is included in its electronic form as a part of the Appendices of this document.

Figure 10. Location of induction sensor on fan motor.

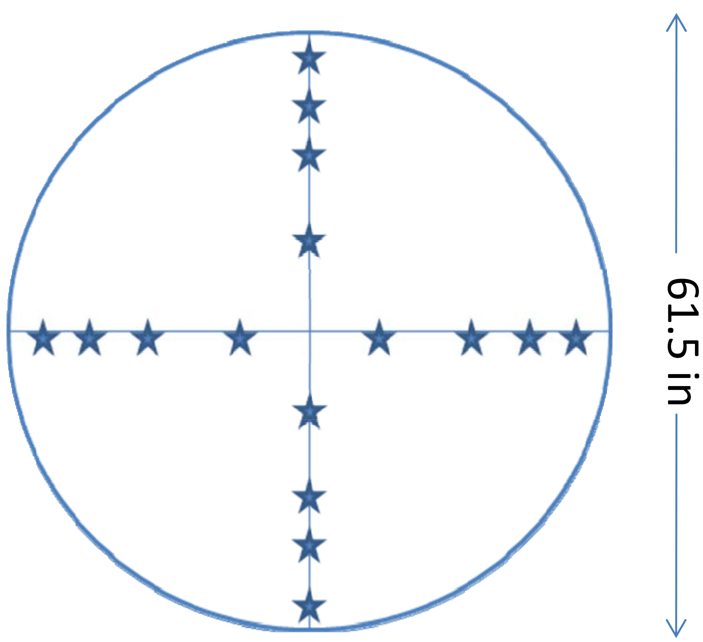

Figure 11. Traverse points in a circular shroud.

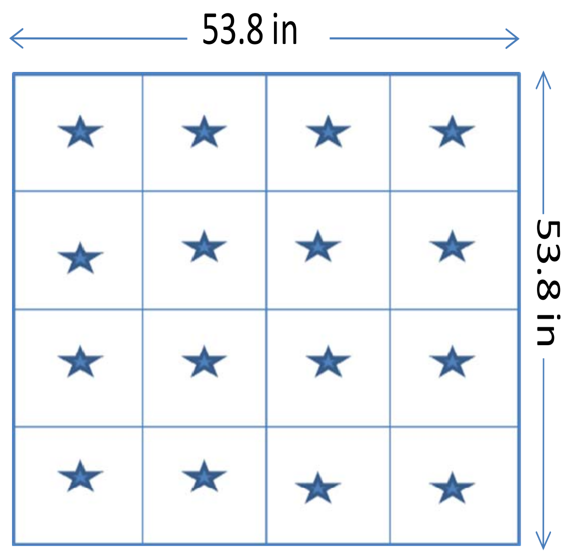

Figure 12. Traverse points in a rectangular shroud.

Table 14. Sampling traverse points for circular shrouds following guidelines in U.S.E.P.A. 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

The in-barn temperature and relative humidity were monitored constantly using microdataloggers (HOBO® H8 Pro, ONSET Computer Corp.) at four different measurement points, roughly near the centroid of each fan bank inside the buildings. These data were collected to assess whether the birds were exposed to relatively constant or variable conditions and to aid in potential gaseous flow rate standardization calculations. The pollutant gas emission factors were determined at the end of each monitoring period by multiplying the building ventilation rate by the difference in concentration between the point of emission, which is an average of the two fan bank measurements (east and west sides) in each building, and the ambient background (inlet) concentration. Additionally, building static pressure, relative to local barometric pressure, was monitored at each fan bank for each building using a Dwyer ±3" W.G. differential pressure transducer.

Real-time Pollutant Measurements

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/valving system, gas analyzers, environmental instrumentation, a computer, a data acquisition system, vacuum pumps, Teflon tubing, and other supplies. The main gas-phase instrumentation was a photoacoustic Field Gas Monitor INNOVA 1412, which selectively measures a wide range of gases/vapor. The instrument purchased for this project was selectivity configured for ammonia (NH_3), ethanol (EtOH), carbon dioxide (CO_2), nitrous oxide (N_2O) and water vapor (H_2O). Water vapor was selected as a measurement parameter so that potential H_2O absorption interferences could be accounted for by the INNOVA 1412. A UV Fluorescence Hydrogen Sulfide Analyzer (Model 450i, Thermo-Environmental) was used in an attempt to measure hydrogen sulfide (H_2S). Table 15 summarizes the instruments used to monitor the pollutants in this study.

Table 15. Measured pollutants and monitoring equipment

Pollutant	Monitoring Instrument
Ammonia (NH_3)	Innova 1412 Photoacoustic Field Gas Monitor
Carbon Dioxide (CO_2)	Innova 1412 Photoacoustic Field Gas Monitor
Ethanol (EtOH)	Innova 1412 Photoacoustic Field Gas Monitor
Nitrous Oxide (N_2O)	Innova 1412 Photoacoustic Field Gas Monitor
Hydrogen Sulfide (H_2S)	Thermo-Env. 450i UV Pulsed Fluorescence H_2S Analyzer
TSP, PM_{10}, $PM_{2.5}$	AirMetrics MiniVol $PM_{2.5}$/PM_{10}, TSP Samplers (filter-based) And MetOne 9722 Optical Particle Counters (OPCs)

<u>Gas-phase Analyzers</u>

The INNOVA 1412 photoacoustic analyzer uses a measurement system based on the photoacoustic infrared detection method and is capable of measuring almost any gas that absorbs infrared light. Through the use of a series of different optical filters, the system is capable of measuring up to five different gases nearly simultaneously. Energy from an infrared light source is reflected off a mirror, passed through a mechanical chopper that causes the light to pulsate, and then through the optical filters, which are designed for the specific, targeted compounds.

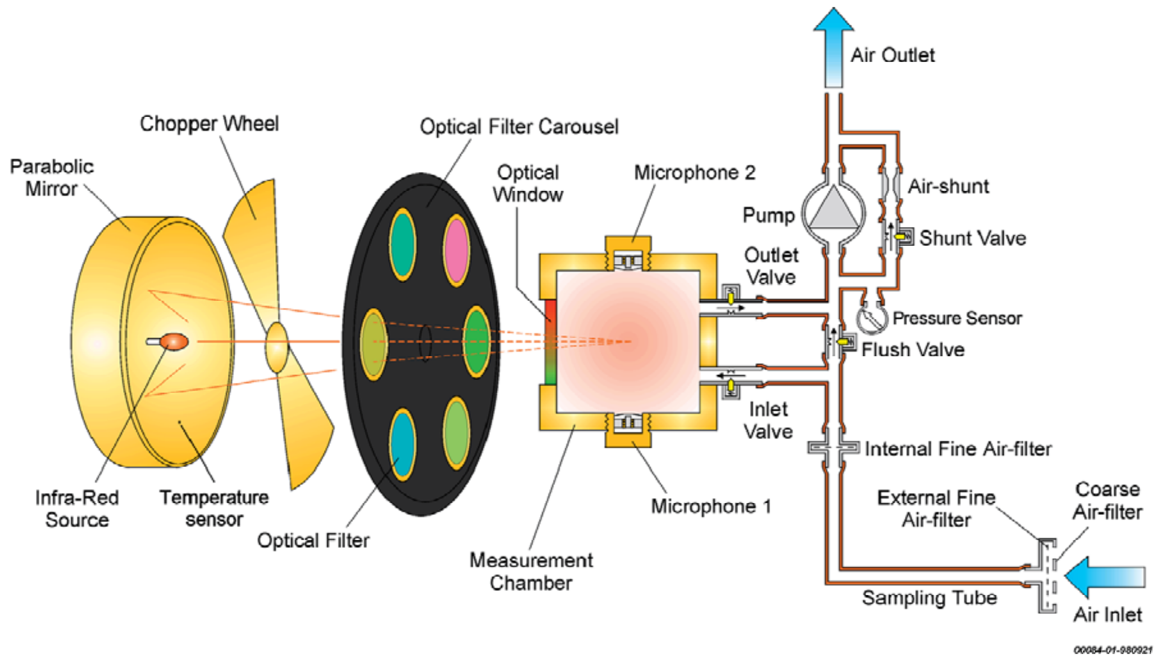

Figure 13. Schematic of a photoacoustic gas monitor. (www.lumasense.dk, 2009).

As shown in Figure 13, the gas being monitored is introduced to the analysis cell, causing the temperature of the gas to increase as it selectively absorbs the light transmitted by the optical filter. Because the light pulsates, the gas temperature increases and decreases, causing an equivalent increase and decrease in the pressure of the gas (an acoustic signal) in the closed cell. Two microphones mounted in the cell wall measure this acoustic signal, which is directly proportional to the concentration of the monitored gas present in the cell. The minimum response time of this type of analyzer may be as low as 5 seconds. The INNOVA 1412, as previously mentioned, can theoretically quantify any gaseous species that absorbs within the infrared spectrum. Table 16 shows the manufacturer's minimum detection for each of the significant targeted components. The operator's manual suggests that the system be returned to the manufacturer annually for calibration and routine maintenance.

Table 16. Manufacturer's detection limits for the pollutants

Gas	**Detection Limit (20°C, 1 atm, t = 5 sec)**
NH_3	0.2 ppm
N_2O	1.5-70 ppm
Ethanol	0.03-0.5 ppm
CO_2	0.03-0.2 ppm

The Thermo-Environmental 450i UV Pulsed Fluorescence H_2S Analyzer consists of an H_2S to SO_2 converter coupled to a pulsed fluorescence SO_2 analyzer. Continuous H_2S monitoring is accomplished by conversion of the H_2S in the sample to SO_2 and its subsequent detection by the SO_2 analyzer. As the SO_2 molecules absorb ultraviolet (UV) light and become excited at one wavelength, the molecules then decay to a lower energy state emitting UV light at a different wavelength. The converter section catalytically converts each H_2S molecule to SO_2

so that the output of the SO_2 analyzer is equal to the concentration of H_2S entering the converter. The electronics subtract the SO_2 result from the total signal of sample passing through the converter and provide an H_2S reading. The monitor can be calibrated using on-site calibrations with certified, commercially purchased SO_2 calibration gases combined with dynamic dilution protocols.

Particulate Measurement

Particulate matter (PM) concentrations at each location were monitored in near real-time (one minute averages) using 8-channel MetOne 9722 Optical particle counters (OPCs). During operation, an OPC was placed in the center of each fan bank, and two were placed on the roof of the MAEMU sampling trailer to monitor ambient PM levels. The OPCs provide near-real-time (20 – 60 second averaging) size distribution and particle count information. The OPCs operate by passing sample air through a right-angle, light scattering detector using a laser diode. The OPCs pull a total of 3 L min^{-1}, 2 L min^{-1} filtered sheath air to protect the system's optics and a sample air flow rate of 1 L min^{-1}. The instrument counts particles and calculates their size using the scattered light. A particle in the sample volume will scatter light from the laser diode, while a 60 steradian solid angle elliptical mirror, located at a right angle to the laser beam, 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 user specified bin for a set time interval. From this information, an optical size distribution can be found.

The OPCs 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 process gives the volume for each particle in the bin and can be multiplied by the number of particles in the bin to obtain total particle volume of all the particles within that bin. The result can be divided by the sample carrier gas flow rate (volume) to get a concentration of the volume of PM per volume of air. As noted above, the OPCs provide data on the number of particles within specified size based on the physical or optical diameter of the particles. However, most ambient PM policies are regulated based on aerodynamic diameter (d_{aero}), which is generally greater than the physical diameter (d_{phys}), as shown by the following relationship:

$$d_{aero} = d_{phys} (\rho_{part}/ \rho_0)^{0.5} \qquad \text{(Hinds, 1999)}$$

where ρ_{part} = particle density (g cm^{-3})
ρ_0 = unit particle density (1 g cm^{-3})

As can be seen, the particle diameters, and therefore the related concentrations, are related by a scalar: the square root of the particle density. If such a scalar can be determined, the optical size distribution information determined from the OPCs can be used to derive aerodynamic, mass-based concentrations and subsequently, emissions.

In order to accomplish this task, portable AirMetrics MiniVol particulate samplers, configured separately for PM_1, $PM_{2.5}$, PM_{10}, and TSP, were used to determine the size-specific mass concentrations for calibration of the real-time, optical particle counters (OPCs). Prior to the barn emission studies, four MiniVols and the OPCs were collocated in one of the barns (west fan bank of Building 5) for one week to collect data and to calibrate the OPCs in reference to mass-based concentrations. Figure 14 shows the array of the OPCs and MiniVols during the calibration exercise inside the fan bank of the poultry building.

Figure 14. Array of OPCs and MiniVols in the poultry building.

The calibration of the OPCs with the MiniVols was a critical part of the project that enabled reliable continuous particulate measurement. The MiniVols can be programmed to operate for a desired time period (generally four hours for these tests) and consist of a single size-segregating sample inlet (impactor), a 47 millimeter (mm) filter cartridge, a flow control system and a pump. The sample inlet can be equipped with different impactor heads that 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^{-1}) and to collect the size-separated particle matter on 47 mm Teflon filters. The filters used in this study were pre-conditioned and pre-weighed at Utah State University's (USU) Utah Water Research Laboratory (UWRL). 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 filter weights reported were the average of a minimum of three consecutive daily weights within ±2.5 µg of the mean.

After the filters were exposed, they were returned to the UWRL for post-test conditioning and a final weight determination similar to the pretest procedures. Once the final filter weights were determined, the mass of PM collected from each impactor was calculated by taking the difference in pre- and post-weights then using the air flow rate and run time to find a size-specific mass concentration.

Calibrations of the OPCs were obtained by comparing the "estimated" OPC size-specific concentrations with the appropriate filter-based, size-specific MiniVol concentrations. The "estimated" OPC concentrations refer to concentrations volume-per-volume (e.g. cm^3 cm^{-3}) basis, which is also equivalent to potential mass-based concentrations assuming a particle density of 1.0 g cm^{-3}. Figure 15 shows a sample calibration of two of the OPCs for PM_{10}. As can be seen, the relationship between the MiniVols and the OPCs are generally well correlated, which indicates the OPCs can be confidently used for real time PM measurements. The remaining calibrations may be found in Appendix A of Ogunlaja (2009). It should be noted that, in practice, the given equations are inverted and solved for "x". In other words, the OPC concentration is "known" and the equivalent, mass-based concentration is calculated.

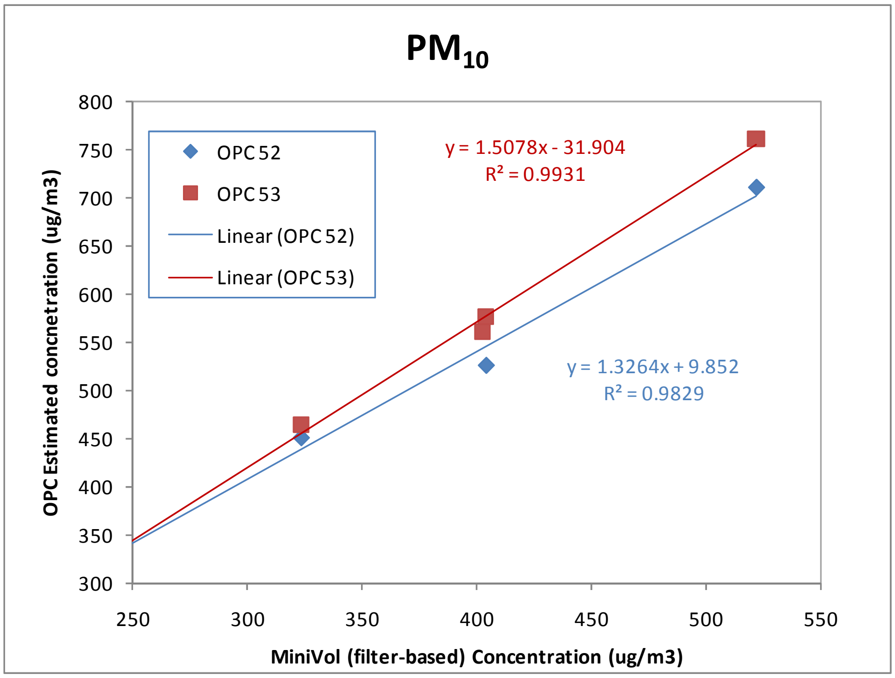

Figure 15. MiniVol (PM_{10} configuration) calibration for OPCs #52 and #53.

Gas-phase Grab Samples (NH_3 and amines)

In this study, a method for identifying and quantifying ammonia and volatile organic amine emissions in ambient and exhaust air at a target poultry facility was developed using ion chromatography (IC). The objective was to determine if amines were present at detectable levels and, if so, to derive emission rates relative to the NH_3 emissions. Amines were separated based upon differences in affinity toward a cation-exchange resin (which provides separation from ammonia and alkali cations) and quantified based on conductivity measurements.

The development of the analytical IC methodologies was an iterative process, developing IC profiles which adequately separated the target compounds, achieved acceptable system run times, and allowed reasonable detection limits. The details of the method development are fully presented in Dinh (2010); however, only the final IC protocol is presented herein.

Impinger sampling for NH_3 and Amines

Previous research (Frank et al., 2006; Audunsson et al., 1989) has shown that amines in livestock air can be more efficiently sampled using sulfuric acid impingers and that these can subsequently be analyzed using ion chromatography (IC). When impingers are used to sample air, a known volume of air is pumped through the glass tube that contains a trapping liquid. In this study, a 0.1 N H_2SO_4 solution was used as the trapping solution. A known volume of air was drawn from the barn ambient air through a series of collecting vessels. The sampling train consisted of two midget bubblers and two midget impingers (Part # 737560-0000, Kimble/Kontes, Vineland, NJ). The first two impingers (#1 and #2) each contained 15 mL of 0.1N H_2SO_4 solution. The first bubbler captured most of the potential amines emitted from the sample source. However, if the acid solution were to become saturated due to high amine concentrations, the second bubbler would retain the surplus amines. The third impinger (#3) was empty to trap any over flow of sulfuric acid from the second bubbler. The fourth impinger (#4) was filled with 15 mL silica gel (6–12 mesh). Sampling ports between impingers were connected with non-outgassing tubing (PolyEtherEtherKetone tubing, 10-mm ID; PEEK). The sampling train was assembled in a ring stand for stability and the first two impingers were placed into a beaker of ice to avoid evaporation. Air was pulled through the sampling train at a rate of 1 L min^{-1}. The flow rate was measured with a DC-Lite primary flow meter (Bios, NJ) that was calibrated before taking the measurement. Each sampling period of 2 hours resulted in a total of typically 120 L of air sampled through the acid solution. Figure 16 shows a schematic drawing of the impinger sampling train employed for these studies.

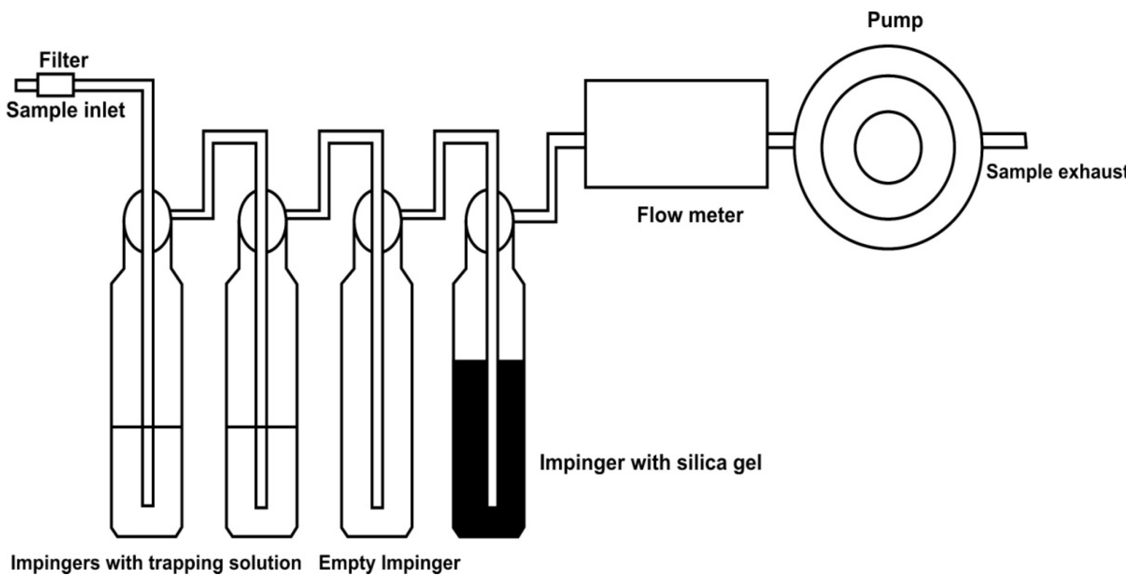

Figure 16. Configuration of the impinger-based sampling train used in the reported studies.

Due to the low temperatures during the cold months, the impinger train was put in an insulated ice bath to keep the acid trapping solutions from freezing. The impinger train was also put in an ice bath during the warmer months to keep the acid trapping solutions from evaporating. Upon reacting with the H_2SO_4, any amines in the air stream are converted to their sulfate salts. For most aliphatic amines, these salts are less volatile and more stable (e.g. more resistant to oxidation and chemical decomposition) than the free amines. Exact start and end times for sampling were recorded. Experimental data were recorded, including locations, tube identification numbers, pump flow rates, dates, times, sampled volumes, and ambient conditions. The total volume of sampled dry gas was calculated by multiplying the average flow rate of the sampling pump by the total sampling time. The average flow rate was calculated by taking the average of flow rates before and after sampling. After the sample was collected for the desired time, the contents of each impinger were poured into a separate 50 mL amber borosilicate glass bottle (VWR, part #15900-030). Deionized water or 0.1 N H_2SO_4 was used to rinse out all interior surfaces of the two trapping solution impingers, as well as their corresponding graduated cylinder. This was done to ensure all sample residues were rinsed out and added to the respective bottles for the two impingers. All samples were placed on ice in a suitable cooler and transported to the USU CAB laboratory for IC analysis. Sample solutions were stored in a refrigerator (4°C) until they were analyzed, which was no later than two weeks after collection.

The impinger sampling sites were set up in the manure barn, Building 4 (manure-belt) and Building 5 (high-rise) once a week. The average sampling time was typically two hours. In the manure barn, the sampling sites were set up throughout the barn to evaluate gradient concentrations of ammonia/amines. At Building 4 and Building 5, sampling sites were rotated routinely to take samples from all active fans throughout the barns. Two impinger samples were taken per week, making a total of eight samples per month. Figure 17 is a photo of the actual impinger sampling train (sampled at the north door of the manure barn, taken on October 6, 2008).

Figure 17. Impinger sampling train at north door of the manure barn on October 6th, 2008.

Ion Chromatography Analysis Protocol Development

The IC used in these experiments was a Dionex model ICS 1000 (Dionex Corporation, Sunnyvale, CA) equipped with electrochemical suppressed conductivity detection. As installed, the ICS 1000 integrated system performs isocratic ion chromatography (IC) separations using conductivity detection. However, as will be discussed subsequently, an HP Series 1050 gradient pumping system was added to the instrument. A Dionex Cation Self-Regenerating Suppressor (CSRS ULTRA, 4 mm) was used to chemically suppress the background conductivity. Manual injections were performed using plastic syringes with an injection volume of 25 µL. Analytical grade (99.5+%, Aldrich) methanesulfonic acid (MSA) was used as the eluent. An IonPac CS17 (250 mm x 4 mm, I.D) was used as the analytical column and a CG17 (50 mm x 4 mm, I.D) was used as a guard column. The IonPac CS17 cation exchanger column has a hydrophilic, carboxylate functionalized stationary phase that was used for analysis of polyvalent and moderately hydrophobic amines. The ICS 1000 system was equipped with Chromeleon

Chromatography Management Systems software that controlled the IC and was used for the data analysis. The eluent flow rate was 1.0 mL min^{-1}. The initial methanesulfonic acid (MSA) eluent concentration was 10 mM. The current applied to the conductivity suppressor was 20 mA. The background conductivity was lower than 0.5 µS and the typical system backpressure was 1600-1700 psi.

Standard solutions were prepared separately for each amine by diluting the pure amine standards with deionized water. For concentration calibration curves (conductivity area vs. amine concentrations), mixture solutions containing ammonia, methylamine, dimethylamine, trimethylamine, triethylamine and n-butylamine were prepared from the pure standard solutions by appropriate dilution in aqueous solutions to generate concentrations of 5, 10, 20, 30, and 40 mg L^{-1} for each of the amine standards. The solutions were subsequently stored in a refrigerator at 4ºC when not in use. New amine standards were made every six months. All standard solutions were prepared using methylamine, dimethylamine, trimethylamine, triethylamine, n-butylamine and ammonia purchased as analytical reagent chemicals (99% purity) from Sigma-Aldrich. Methanesulfonic acid (MSA) that was used as an eluent in ion chromatography (> 99% pure) was also supplied by Sigma–Aldrich. Water for all chromatography was purified using a Milli-Q system (Millipore, Bedford, MA, USA) to produce 18.2 MΩ water.

Initially, an isocratic separation of the ammonia and amines standards was developed employing MSA and water as the solvent system on the ICS 1000 system. However, it was found that a suitable separation of the organic amines could not be achieved using isocratic chromatographic conditions. The amine standards exhibited asymmetric peaks using isocratic elution conditions.

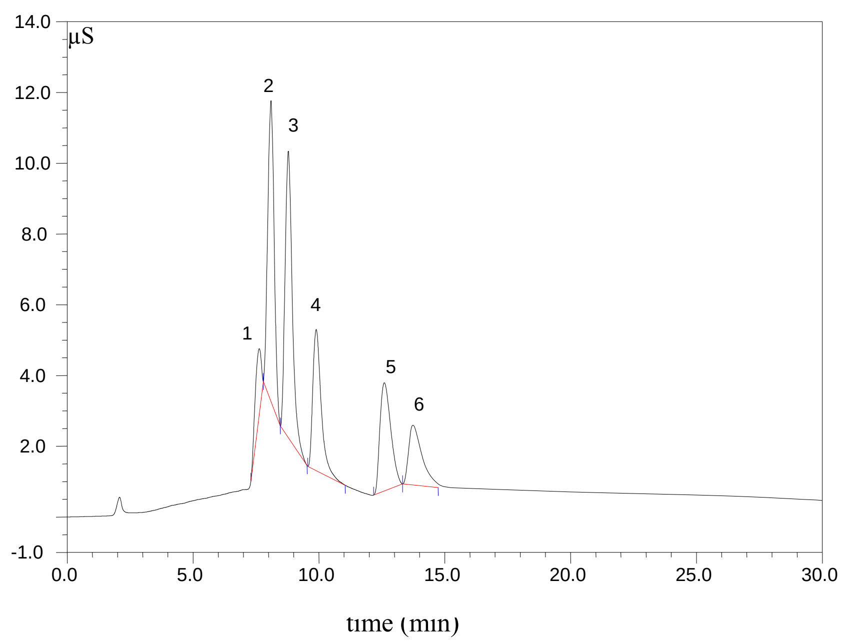

Figure 18. Gradient chromatogram of the standard mixture of amines; * solvent peak, 1- Ammonia, 2-Methylamine, 3- Dimethylamine, 4- Trimethylamine, 5- n-butylamine, 6- triethylamine.

After several isocratic attempts, an optimized gradient elution solvent program was developed employing 10 mM MSA and deionized water in varying compositions during the separation. To allow for a gradient program to be employed, the single pump of the ICS 1000 system was by-passed and a gradient pumping system from a series 1050 (Hewlett Packard, PA, USA) liquid chromatograph was used to provide the necessary solvent gradient for the separation of the amines standards. Figure 18 shows the standard amine mixture separated using the optimized gradient program. As can be seen, Figure 18 illustrates the resolution needed for quantification of close eluting peaks by using a gradient chromatographic procedure instead of isocratic elution. The retention times with standard deviations (s/n=3) observed for ammonia, methylamine, dimethylamine, triethylamine, n-butylamine and triethylamine were: 7.63 ± 0.04 min, 8.09 ± 0.06 min, 8.78 ± 0.03 min, 9.89 ± 0.09 min, 12.60 ± 0.12 min and 13.78 ± 0.11 min, respectively.

The gradient program found to be optimal was an MSA change from 20 to 80 mM MSA in 8 minutes, followed by holding at 80 mM MSA for 9 minutes. A reverse gradient was employed over 5 minutes to return the solvent to 20 mM MSA starting conditions. The system was then re-equilibrated for 8 minutes. As with the initial isocratic tests, the IC flow rate employed was 1.0 mL min^{-1} and the sample injection volume used 25 μL. The gradient program for the amines separation is shown in Table 17. The gradient elution program resulted in the amine standards being well separated in less than 15 minutes. The standards were run as three replicate samples using the developed gradient elution program.

Table 17. Gradient eluent profile for amines separations

Time (min)	A%	B%	Flow rate (mL min^{-1})
0	20	80	1.00
8	80	20	1.00
17	80	20	1.00
22	20	80	1.00
30	20	80	1.00

A: 10 mM MSA in water; B: deionized water.

One of the disadvantages of using a solvent gradient for separation is a longer analysis time. In the isocratic separation, the total analysis time was 11 minutes (with 10 mM MSA as eluent), and in the separation employing solvent gradient conditions, the total analysis time was 15 minutes plus the time needed to re-equilibrate the column. However, greater peak separation was obtained by employing gradient relative to isocratic elution, which should improve quantification.

In order to determine the detection limits for the amines, each of the pure amine standards (ammonia, methylamine, dimethylamine, trimethylamine, n-butylamine and triethylamine) was spiked into a known volume of deionized water to give final concentrations in the range of 10 to 100 (mg L^{-1}). Under optimized experimental conditions (gradient conditions), all six analytes showed good linear calibration curves for the concentrations vs. area response. Limits of detection (LOD) in the aqueous (IC) solutions were calculated from individual amine calibration curves using three times the average baseline noise (s/n=3) as the LOD. Detection limits of ammonia, methylamine, dimethylamine, trimethylamine, n-butylamine and triethylamine were found to be: 196 μg L^{-1}, 171 μg L^{-1}, 128 μg L^{-1}, 98 μg L^{-1}, 72 μg L^{-1}, and 56 μg L^{-1}, respectively.

The recoveries were between 76.8% and 88.6%. Detection limits and the recoveries (%) of the amines are listed in Table 18.

Table 18. Limit of detection and recovery percentages of target amine compounds

Analyte	Range (ppm or mg L^{-1})	LOD (aq) (s/n=3) (ppb)	LOD[a] (air) (ppb)	Retention Time (min)	Retention Time Std Dev (min)	Recovery (%)
Ammonia	10 -100	196	128	7.63	0.04	88.6
Methylamine	10 -100	171	110	8.09	0.06	82.5
Dimethylamine	10 -100	128	52	8.78	0.03	81.3
Trimethylamine	10 -100	98	27	9.89	0.09	78.8
N-butylamine	10 -100	72	19	12.60	0.12	79.1
Triethylamine	10 -100	56	11	13.78	0.11	76.8

LOD[a] see appendix C in Dinh (2010) for a sample calculation.

For the analysis, the collected impinge samples were first diluted with deionized water to a final volume of 50 mL for subsequent analysis (APHA, 1977). The volume of each individual amine compound in the original air sample was calculated as shown below (see Appendix A in Dinh, 2010, for a sample calculation):

$$V_a = (N)(0.1)(24.04)(0.001) / (MW_a)$$

where:

V_a = Volume of individual amine gas in the sample of gas taken from the source
N = Average concentration of amine (mg L^{-1}) in the solutions obtained from the two impingers ((Impinger 1 concentration + Impinger 2 concentration)/2)
0.1 = Conversion factor, assuming the sample in each of the two impingers was diluted to 50 mL (0.10 L total volume)
24.04 = Liters of ideal gas per mole of substance
0.001 = Factor to convert mg L^{-1} to g L^{-1}
MW_a = Molecular weight of amine analyte
*: the amine concentrations from impinger 1 and 2 were calculated base on the conductivity measurements run by the IC.

All of the calculated sample volumes were subsequently corrected to standard temperature and pressure conditions (20ºC, 760 mm Hg). The volume of gas sample was corrected to standard conditions follow by the equation (see Appendix B and C of Dinh, 2010, for a sample of calculation):

$$V_{m(std)} = V_m(T_{std}/T_m)[(P_{bar} + \Delta H/13.6)/P_{std}]$$

where:

$V_{m(std)}$ = Volume of gas sample, corrected to standard conditions
V_m = Volume of gas sample at actual condition
T_{std} = Standard absolute temperature, 293°K
T_m = Absolute average temperature during sampling, °K
P_{bar} = Barometric pressure at the sampling site, mm Hg
P_{std} = Standard absolute pressure, 760 mm Hg
ΔH = Impinger pressure change during sampling period, mm of H_2O
13.6 = Specific gravity of mercury

The concentration (C_a, reported in ppm,) of each amine analyte present in the gas sample was calculated:

$$C_a = (V_a/V_{m(std)}) \times 10^6$$

Total Kjeldahl Nitrogen (TKN) and NH_3 Analysis for Nitrogen Balance

As previously discussed, the total nitrogen emissions from the target facility were also assessed by analyzing the ammonia content and total Kjeldahl nitrogen (TKN) of the animal feed, production, and waste, resulting in determination of the nitrogen loss to the atmosphere. In order to experimentally measure the amount of nitrogen released into the atmosphere as ammonia, TKN values were obtained weekly for animal feed, eggs, and manure. The difference between the amount that entered the chickens in their feed and that exited the chickens in their eggs and manure should be correlated to the amount of ammonia released from the system. In addition to the TKN and NH_3-N analysis, the pH and moisture content of samples were also measured to further correlate the nitrogen emission.

Sample Collection Protocol

The chicken manures were sampled at the three different barns at the test facility: the manure barn, Building 4 (manure-belt) and Building 5 (high-rise). The manure barn held the older manure from Building 4. Within Building 4, the manure was being removed from the housing barn via the manure-belt system approximately twice per week. Barn 5 employed a manure storage method in which the wastes were stored in a pit beneath the housing level. Several sub-samples of chicken manure were taken to produce a composite sample. Due to the plentiful litter and animal feathers, sampling was conducted using a small shovel. Manure was collected by scooping into a bucket from several random locations in the manure pile and then manually mixing them in the bucket. Manure was stored in Ziploc bags. Manure, along with the animal feed and eggs, which were provided by the farm manager, were collected weekly from May 2008 to November 2009. After collection, the manure, feed and egg samples were transported to the USU CAB laboratory and stored in the refrigerator at 4°C prior to analysis (USEPA, 2001a).

Total Kjeldahl Nitrogen Analysis

The Kjeldahl method for nitrogen analysis is composed of three distinct steps: digestion, distillation, and titration. The purpose of the digestion step is to break the target chemical substance down to simple chemicals and ionic structures. The sample is first digested in strong sulfuric acid in the presence of a catalyst, which helped in the conversion of the amine nitrogen to ammonium ions (USEPA, 2001a). To accomplish this, one to two grams of the samples (manure, feed or egg) were placed into an 800 mL Kjeldahl flask with 25 mL of concentrated sulfuric acid (H_2SO_4). About 15 g of propac powder, which contains copper and potassium sulfate, was added into the flask to act as a catalyst and to increase the boiling point of the acid so as to decrease the time needed for digestion. The digestion tube was placed into a digestion block where it was heated to the boiling temperature of the mixture. The temperature was maintained at 150 °C for 1 hour, and then, at 400 °C for 2 hours. Digestion was usually completed after a total of three hours. Figure 19 shows a picture of the digestion apparatus before the sample broke down into the ammonium sulfate $(NH_4)_2SO_4$.

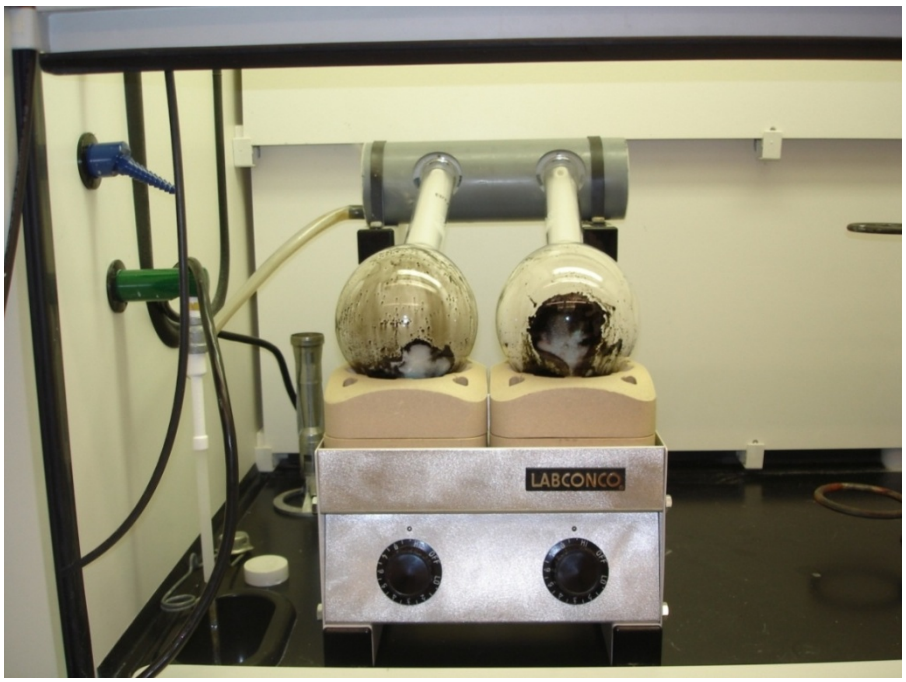

Figure 19. Digestion apparatus during the digestion.

After all of the inorganic species in the sample have been converted to ammonium sulfate $(NH_4)_2SO_4$, the samples changed from black to a clear greenish color as shown in Figure 20. Blank solutions were analyzed in the same way, and their measurements were considered in order to determine the nitrogen concentrations in the samples.

After the sample had been completely digested, it was set aside to cool to room temperature for about an hour before continuing to the distillation step. Distillation involved the separation of ammonia–nitrogen from the digestate. After the sample had cooled to room temperature, DDI water (300 mL), acetyl tributyl citrate (defoamer, 4-5 drops) and sodium hydroxide NaOH (60 mL) were added to form Na_2SO_4, H_2O and NH_3. Glass beads were also added to reduce excess boiling. The purpose of adding NaOH was to raise the pH and convert ammonium (NH_4^+) ions to gas-phase ammonia (NH_3) so that it was possible to separate the nitrogen compounds by distilling the ammonia and collecting the distillate in a suitable trapping solution. In this study, boric acid (Kjelsorb solution, 100 mL) with a color indicator was used as the trapping solution. The water and NH_3 (200 mL) were distilled into the boric acid solution as shown in Figure 21. The ammonia was bound to the boric acid in the form of ammonium borate.

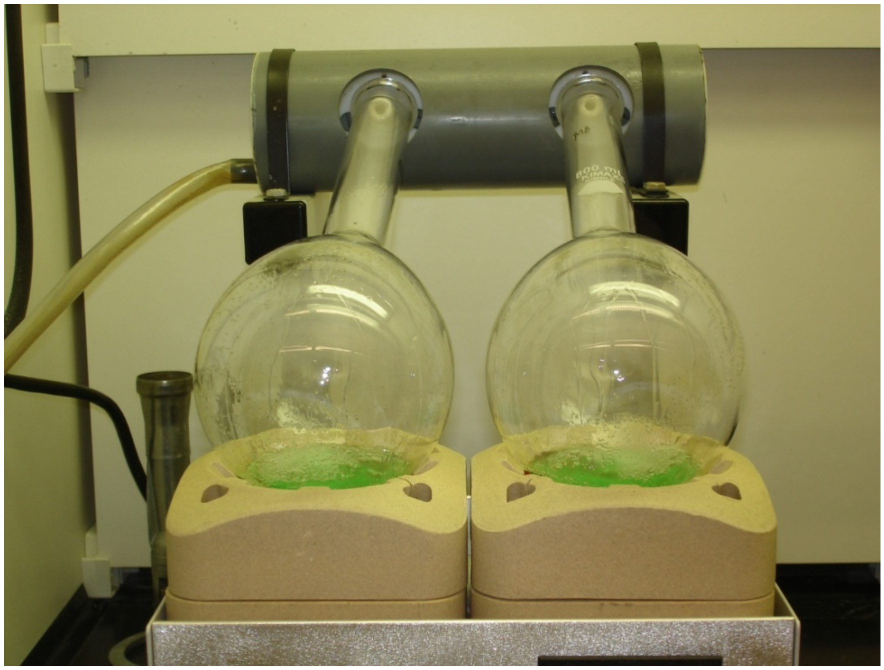

Figure 20. Digestion apparatus after the digestion has been completed.

Figure 21. Distillation apparatus.

After the sample had been with distilled, it was back titrated with standardized dilute sulfuric acid (0.1 N H_2SO_4). The volume of the acid required for the back titration was then used to determine the nitrogen content of the sample. A nitrogen-containing standard (EDTA disodium dihydrate) was also tested using the same procedures within 12 hours of the samples to ensure that the results were reliable and reproducible.

The amount of total Kjeldahl Nitrogen (TKN) (in units of % N) in the samples was then calculated (see Appendix D in Dinh, 2010 for a detailed sample of calculation) as follow:

$$TKN = [Titrant_{sample} / \text{sample weight (g)}] \times H_2SO_4 \text{ normality} \times 1.4007$$

The reagents used in this experiment are concentrated sulfuric acid H_2SO_4 (18 M), concentrated sodium hydroxide NaOH (40% w/w), propac powder, saturated boric acid solution with indicator, and acetyl tributyl citrate 99% pure (purchased from Acros Organic). All reagents were of analytical grade. The digestion and distillation components for the experimental apparatus, as well as the block heater and 800 mL Kjeldahl flasks, were purchased from Labconco.

Ammonia content analysis

The ammonia content analysis method was nearly identical to the TKN method, but the sample was not digested. The ammonia in a manure sample was distilled away from the rest of the sample, at which point it was captured in a dilute boric acid solution containing a bromocresol green methyl red indicator. The ammonia concentration of the distillate was then determined by titration with sulfuric acid (Bremner and Keeney, 1965). The procedure started from the addition of the water (50 mL for standard, 200 mL for samples), defoamer, and sodium hydroxide to the sample (about 2 gram of manure). Because a smaller amount of water was used, only 50 mL was distilled and collected for the standards, and only 150 mL were distilled and collected for the samples. The distilled samples were greenish clear and were titrated with 0.1 N H_2SO_4 to back calculate the ammonia content. The equivalent point was a dark purple color. This procedure quantified only the nitrogen originally present in the sample as ammonia. This analysis was only performed on manure samples and was validated by titration of an ammonium chloride standard.

Similar to the calculation for TKN, the NH_3-N (mg NH_3 g_{manure}^{-1}) in the samples was calculated as follows (see Appendix Ein Dinh, 2010, for a sample of calculation):

$$NH_3\text{-}N = [Titrant_{sample} \text{ (mL)} / \text{sample weight (g)}] \times H_2SO_4 \text{ normality} \times 1.4007$$

Nitrogen balance calculation

An ammonia-nitrogen (NH_3-N) balance for an animal housing facility can provide a check for airborne NH_3 emissions that have been calculated based on measured NH_3 concentrations in the building's air exchange system. NH_3-N losses were estimated using a mass balance approach (Keener et al., 2002). Nitrogen balances for animal production systems enable prediction of upper limits on NH_3 emission (Keener and Zhao, 2008). Figure 22 is a schematic of an animal-production system viewed as a controlled system with inputs and outputs (Keener and Michel, 2005; Keener and Zhao, 2008). The schematic was generalized for the case of body growth, milk and egg production. Analysis of this production system for NH_3-N assumed no other gaseous losses of nitrogen (N).

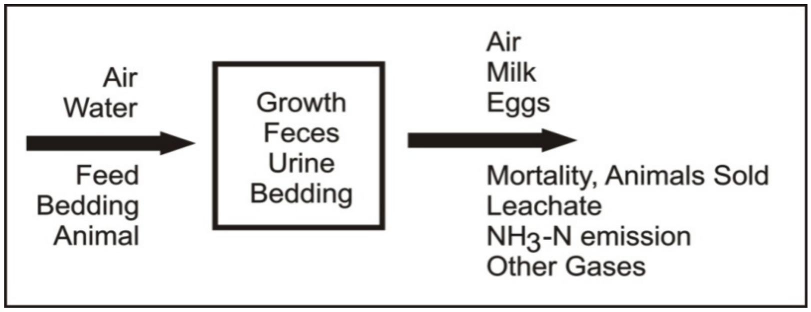

Figure 22. Schematic of an animal production system with input, and output variables (Keener and Zhao, 2008).

The daily nitrogen fluxes in inputs (feed) and outputs (eggs) were calculated as follows (see Appendix F in Dinh, 2010, for detailed calculations):

Daily nitrogen flux (NF) in feed (mg bird^{-1} day^{-1}):

$$NF_{feed} = R_{Nfeed} * m'_{feed} / n_b$$

Daily nitrogen flux (NF) in eggs (mg bird^{-1} day^{-1})

$$NF_{egg} = m_{egg} * \zeta_{egg} * R_{Negg}$$

Total nitrogen flux (NF) in manure (mg bird^{-1} day^{-1}) was determined according to:

$$NF_{man} = R_{N:man} * w_{man}$$

The NH_3 an emission per manure storage period was calculated as followed:

$$EM_{NH3} = (NF_{feed} - NF_{egg} - NF_{Dman}) \times 1.2143 \quad (18)$$

where:

R_{Nfeed} (mg g^{-1}) = TKN content of feed
m'_{feed} (kg barn^{-1} day^{-1}) = Daily feed consumption rate
n_b (birds barn^{-1}) = Number of animals
m_{egg} (g) = Average egg mass
ζ_{egg} (egg bird^{-1} day^{-1}) = Production egg efficiency (obtained from farm manager)
R_{Negg} (mg g^{-1}) = TKN content of egg
$R_{N:man}$ (mg g^{-1}) = TKN content of manure
w_{man} (tons barn^{-1}) = Manure production rate (obtained from farm manager)
1.2143 is used to convert molar mass of N (14) to molar mass of NH_3 (17)

Manure composition significantly affects its odor emission and individual chemical components. Therefore, the solids-to-liquids ratio of manure was an important property to be measured. Moisture content of manure has a major effect on NH_3 release from the manure (Liang et al., 2005). Higher moisture content results in a higher ratio of NH_3/TKN_{Manure} in the stored manure, which result in a higher percentage of N loss (National Research Council, 2003). In this study, all samples were analyzed to determine both pH and moisture content. To analyze for the moisture content, a well mixed sample aliquot having a wet weight between 25 and 50 g was dried in the oven at 103°C to 105°C in order to drive off all water in the sample. This step allowed for the determination of total solids. After cooling, the total solid portion of the sample was heated to 550°C in a muffle furnace to cause the volatile solids to be released. Once the sample was again cooled, the remaining residue represented the fixed solids portion (USEPA, 2001b).

The volatilization of ammonia from any manure management operation can be highly variable depending on total ammonia concentration, temperature, pH, and storage time. Emissions depended on how much of the ammonia-nitrogen in solution remains as volatile ammonia or reacts to form non-volatile ammonium (NH_4^+). High pH and high temperature favor higher neutral ammonia concentrations and cause greater ammonia emissions (National Research Council, 2003).

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 Meteorological Station located at the top of the north side of the manure building. The sensors were mounted approximately 7.4m above the ground level, and the base station was housed in the sampling trailer (MAEMU - refer to Figure 8).

RESULTS & DISCUSSIONS

Real-time Gaseous & Particulate Emissions

Environmental Parameters

Figure 23 shows a typical example of the diurnal, hourly averaged internal temperatures and relative humidities as measured on September 16, 2008. The HOBO temperature and relative humidity sensors where placed in each of the two fan banks in the high-rise barn (Building 5) and showed consistent trends for both measured parameters over each 24-hr period shown, except between the time of about 10:22 am (MST) and 19:22 pm (MST). The observed trends are not unexpected due to the temporal nature and connective relationships of these observed parameters. During the sampling period of September 16, 2008, the observed average temperatures for the west and east fan banks of the high-rise building were 22.6±5.4 and 18.6±2.1°C, respectively, and the average inside relative humidities during the same period were 37.2±10.6 and 47.7±9.3%, respectively.

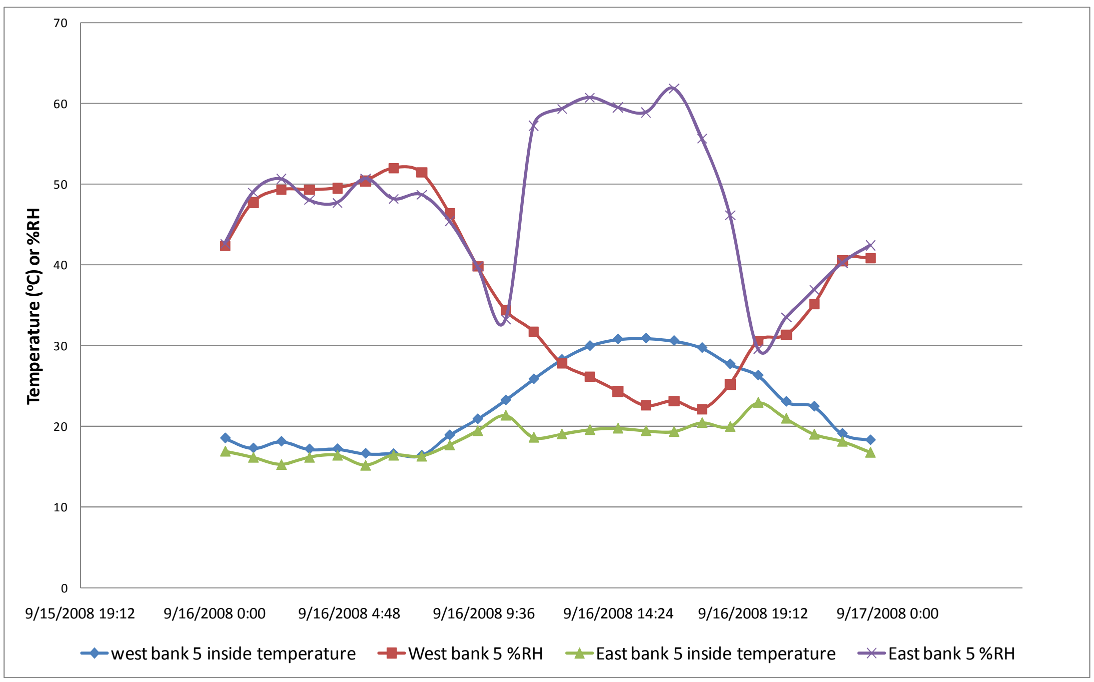

Figure 23. Typical diurnal profile of internal temperature and relative humidity for Building 5 (high-rise) as measured on Sept. 16, 2008.

Figure 24 shows the seasonal changes observed in the temperature and relative humidities over the seasonal sampling period. The jump in trend observed around September - November was as a result of the high ambient temperatures experienced during the sampling period and changes in fan operation, especially during September and October, as will be discussed in the ventilation rate plots of the next section. Also, the similarity in temperature and percent RH pattern observed across the building, regardless of the different banks, shows that the design of the poultry building to automatically maintain an optimum temperature for the poultry at all times is in good condition. Over the six months shown, the observed average temperatures for the west and east fan banks of the high-rise building were 41.3±20 and 39.5±23°C, respectively and the average inside relative humidities during the same period were 43.5±7.5 and 48.2±8.4%, respectively. The daily profiles and monthly average temperatures and relative humidities for the west and east fan banks inside the high-rise (building 5) were comparable over the observed sampling period as can be found in Appendix B of Ogunlaja (2009), one of the theses developed under this project.

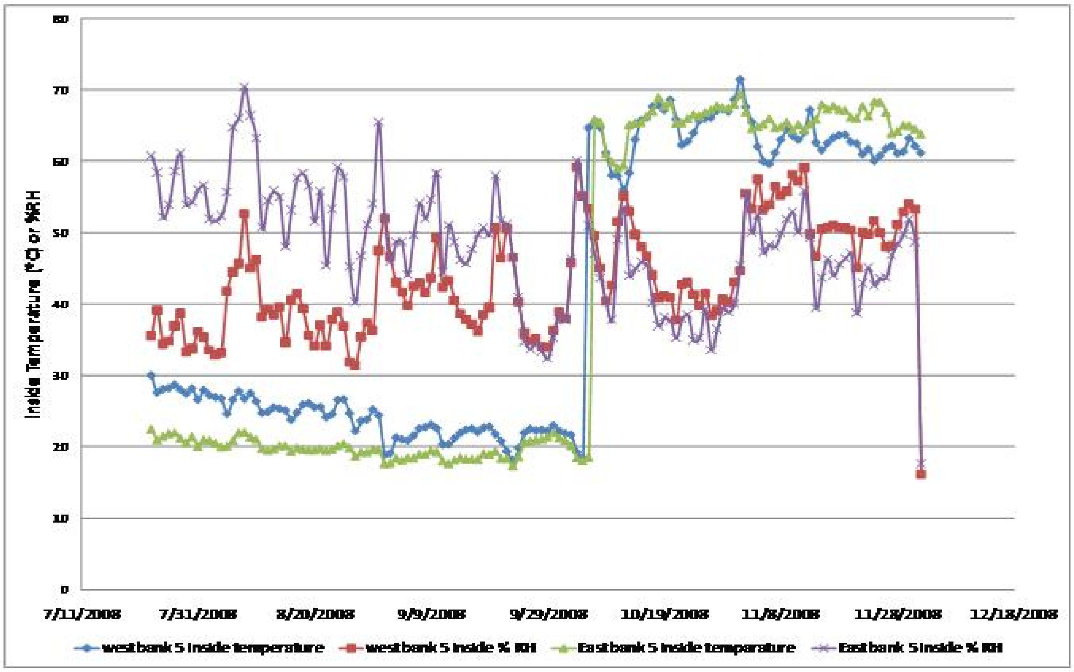

Figure 24. Internal temperature and relative humidity measurements for Building 5 (high-rise) for the last six months of 2008.

Similarly, the two HOBO's placed in the two fan banks in the manure-belt barn (Building 4) showed consistent trends for both measured parameters over the 24-hr period except between the time of about 10:22 am (MST) and 19:22 pm (MST), which was also a consistent pattern over the observed sampling period for the manure-belt building (Figure 25). The pattern was akin to that observed inside the high-rise building over the same sampling period. During the sampling period of September 16, 2008, the observed average temperatures for the west and east fan banks of the manure-belt building were 22.8±5.1 and 18.8±1.8°C, respectively, and the average inside relative humidities during the same period were 37±10 and 45±7.8%, respectively. Sample plots for other days may be found in Appendix B of Ogunlaja (2009).

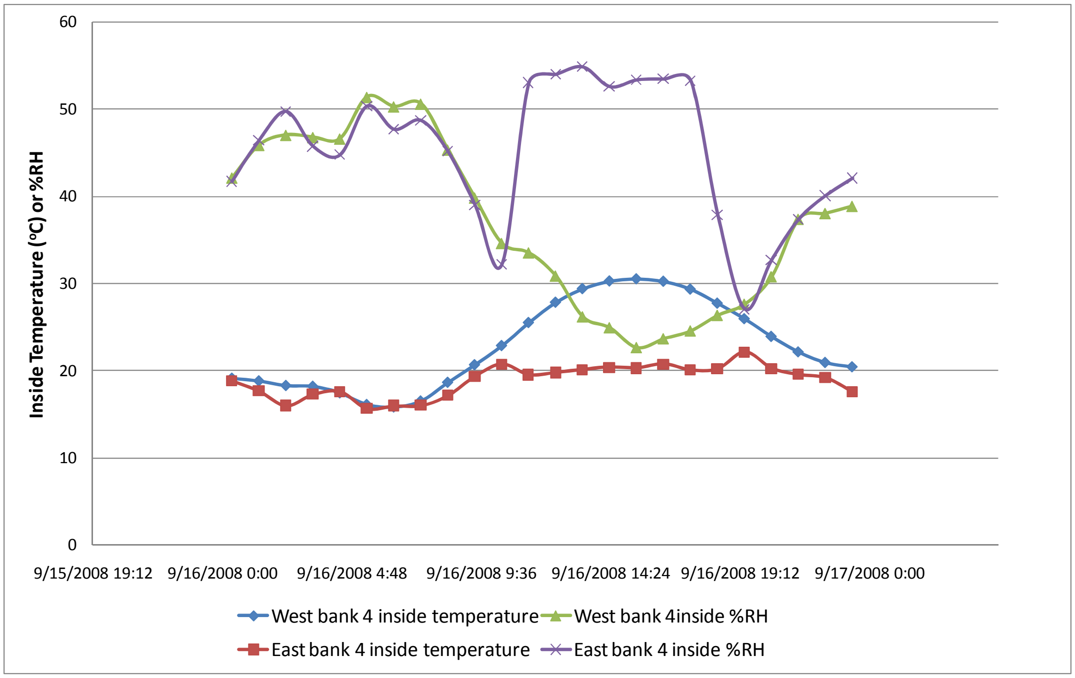

Figure 25. Internal temperature and relative humidity measurements for Building 4 (manure-belt) as measured on Sept. 16, 2008.

Figure 26 shows the internal temperature and relative humidity profile for Building 4 (manure-belt) over the sampling period (seasonal variation) similar to Figure 24 for the high-rise barn. There was a consistent pattern across the building for both inside building temperature and %RH, regardless of the banks sampled. This reveals that the inside building conditions environmental controllers were working as desired so as to maintain an optimum condition for the poultry. Likewise, the temperatures and relative humidities, for the west and east fan banks, inside the manure-belt Building 4 were essentially similar to that observed in Building 5 (high-rise). Therefore, the same explanation for the temperature and %RH profile for the high-rise can also be attributed to the manure-belt. In addition, the reduction in the %RH at the point of an increase in the building temperatures was as a result of the increase in the ventilation rate of the building during those sampling periods. Furthermore, over the six months seasonal period, the observed average temperatures for the west and east fan banks of the manure-belt barn (Building 4) were 40.2±19°C and 36.8±20°C, respectively, and the average inside relative humidities during the same period were 44.1 ±7.9 and 49±8.1%, respectively. The detailed daily and monthly average temperature and relative humidity over the sampling period may be found in Appendix B of Ogunlaja (2009).

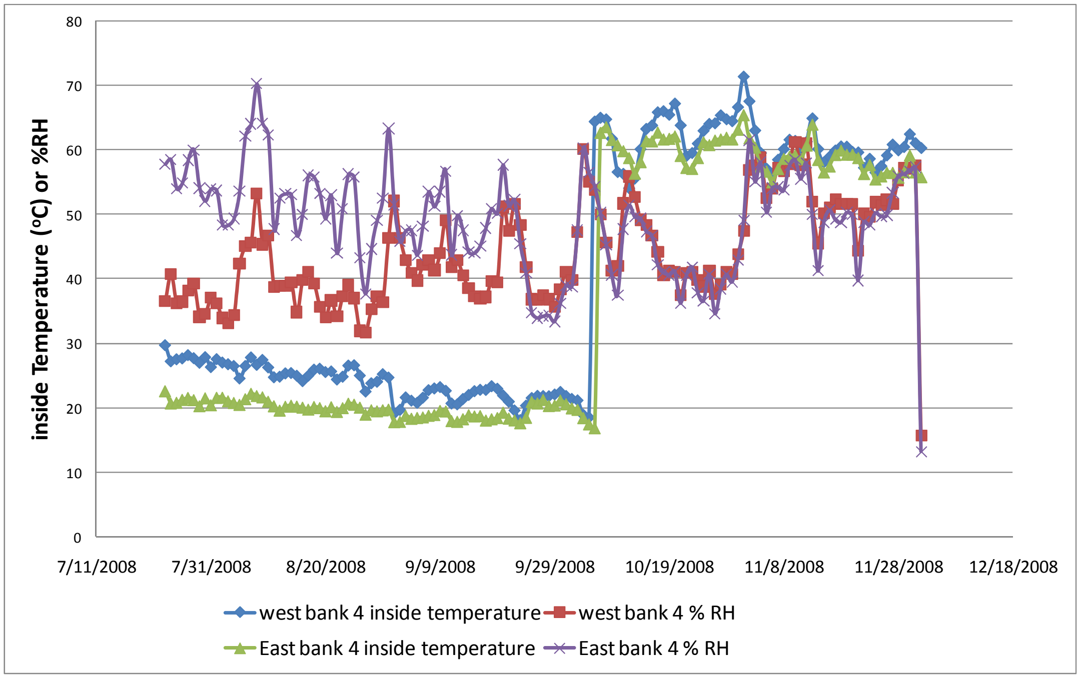

Figure 26. Internal temperature and relative humidity profile for building 4 (manure-belt) for the last six months of 2008.

Ventilation rates

The air flow rate during the monitored periods was consistently higher in the high-rise barn (Building 5) than in the manure-belt barn (Building 4). The ventilation rates ranged from 0.80 m^3 hr^{-1} $bird^{-1}$ to 4.80 m^3 hr^{-1} $bird^{-1}$, with an average of 2.02 m^3 hr^{-1} $bird^{-1}$ for the high-rise barn and from 0.80 m^3 hr^{-1} $bird^{-1}$ to 6.0 m^3 hr^{-1} $bird^{-1}$, with an average of 2.20 m^3 hr^{-1} $bird^{-1}$ for the manure-belt building over the sampling period of September, October, November, and December 2008 and January 2009. The data before September 2008 were lost due to computer failure. Once again, summary data are presented herein and the detailed data can be found in Ogunlaja (2009).

Figures 27 and 28 show the sample hourly averaged diurnal ventilation rates profile observed for a typical September eight day sampling period (mid September 2008) for the west and east fan banks of the high-rise barn (Building 5). As can be seen, although there was some inequity between the fan banks within the same building, the flows for each day showed a similar pattern and nearly the same flow rates. For comparison, the internal building temperature measurements during the same periods are shown in Figures 29 and 30. As can be seen, higher temperatures are reflected with higher ventilation rates, a characteristic observed to be similar to both management techniques throughout the sampling period. This was due to the automatic mode of operation of the ventilation fans in relation to the inside building temperature so as to maintain an optimum temperature for the poultry.

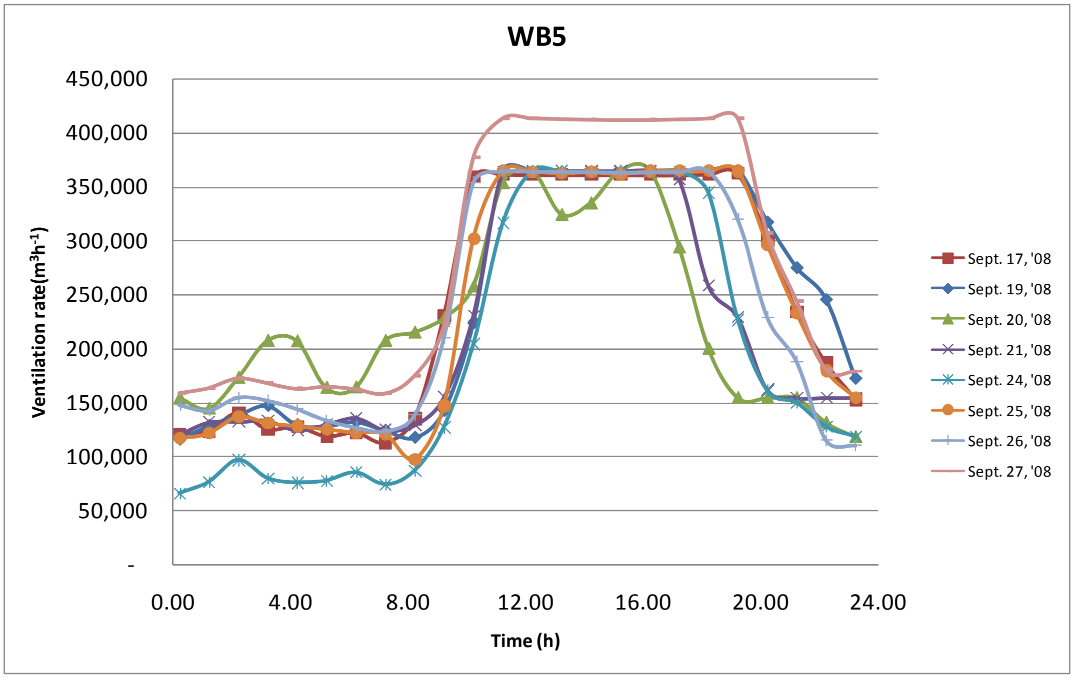

Figure 27. Typical diurnal, 1-hr average ventilation rates for the west fan bank of Building 5 (high-rise) for the eight successive sampling periods.

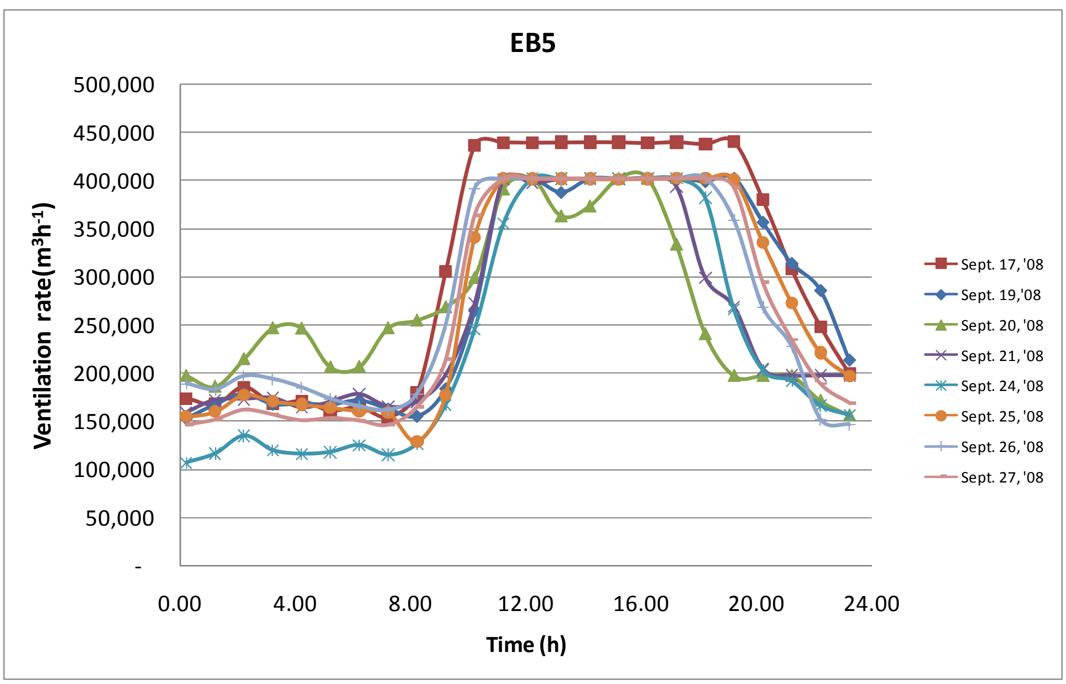

Figure 28. Typical diurnal, 1-hr average ventilation rates for the east fan bank of Building 5 (high-rise) for the eight successive sampling periods.

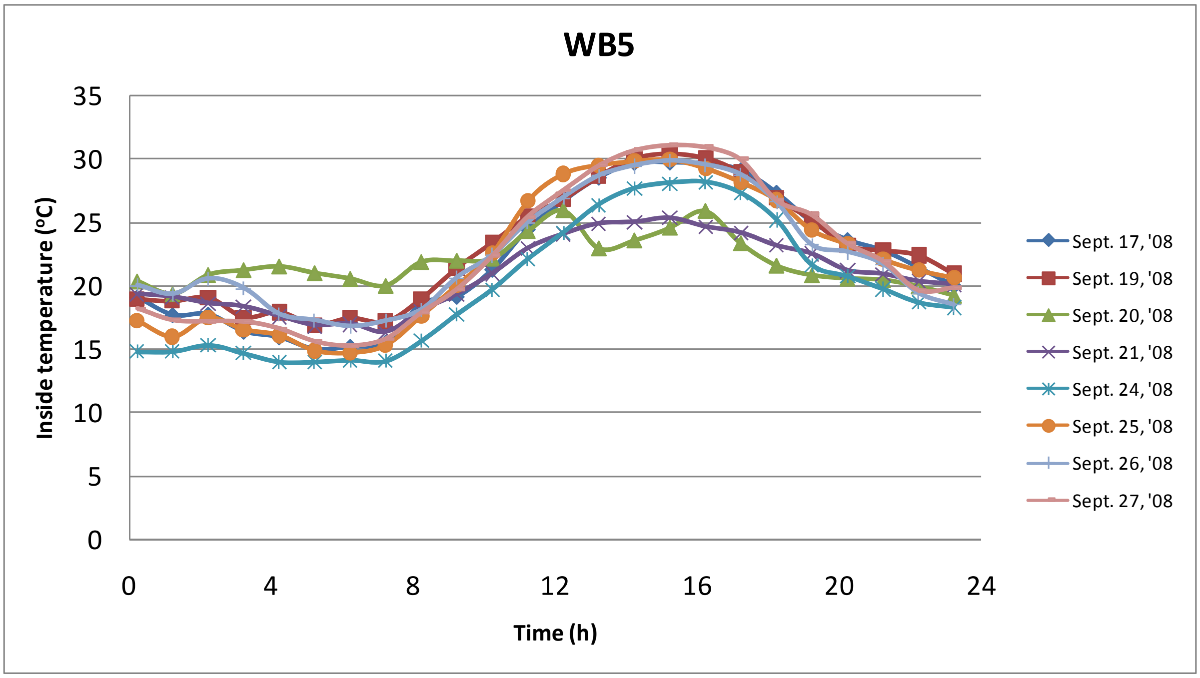

Figure 29. Typical diurnal, 1-hr average internal temperatures for the west fan bank of Building 5 (high-rise) for eight successive sampling periods.

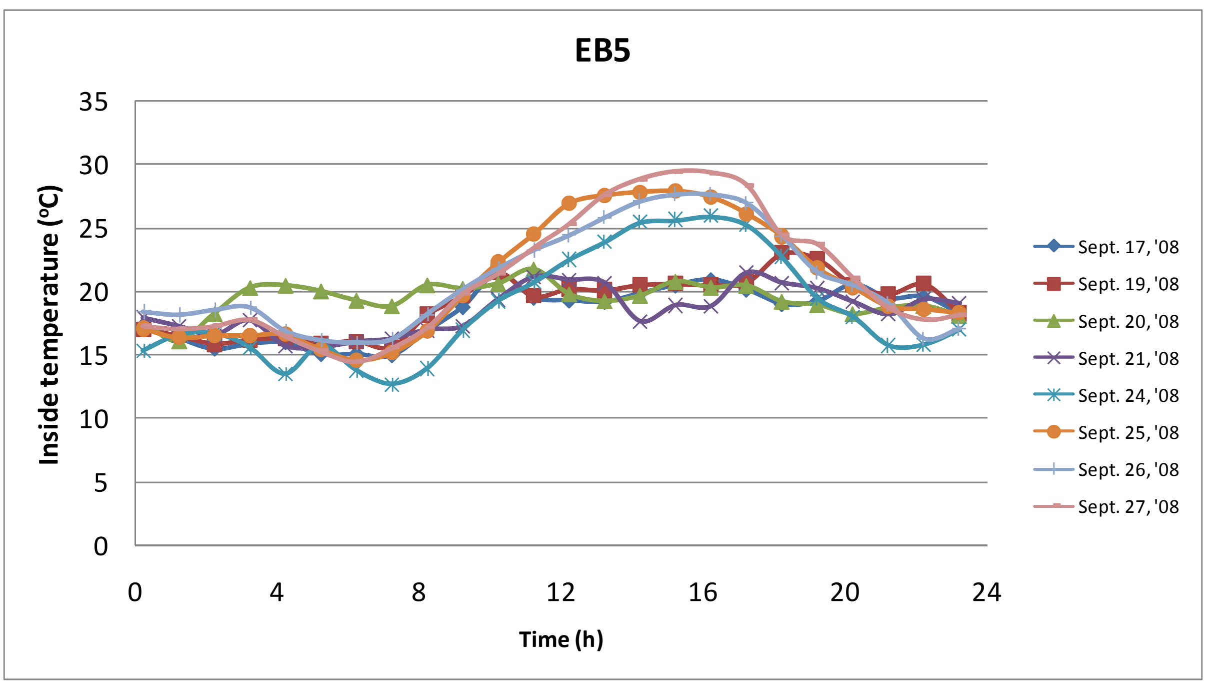

Figure 30. Typical diurnal, 1-hr average internal temperatures for the east fan bank of Building 5 (high-rise) for eight successive sampling periods.

Figures 31 to 36 show the average daily ventilation rates, based on hourly averages, for the four fan banks (two for each barn) and the total building ventilation rate over the sampling periods for Building 5 (high-rise) and Building 4 (manure-belt). All six figures show a decreasing trend as the sampling period progressed from the warmer months into the colder months. This trend was a result of the reduction in the number of fans in operation as the average ambient temperature of the sampling location cooled with the seasonal changes. The reduction in the ambient temperature caused a reduction in the inside building temperature as observed in the previous section, thereby automatically reducing the number of fans needed in order to attain an optimum temperature inside the buildings. Toward the end of the year, approaching the winter season, most of the fans were not in operation as can be seen in each of the Figures 31-36, but is especially evident in Figures 31, 32, 34, and 35 wherein the different colors represent each individual fan. As can be seen, during the colder winter months, it was not uncommon for only two or three fans to be operating in each fan bank.

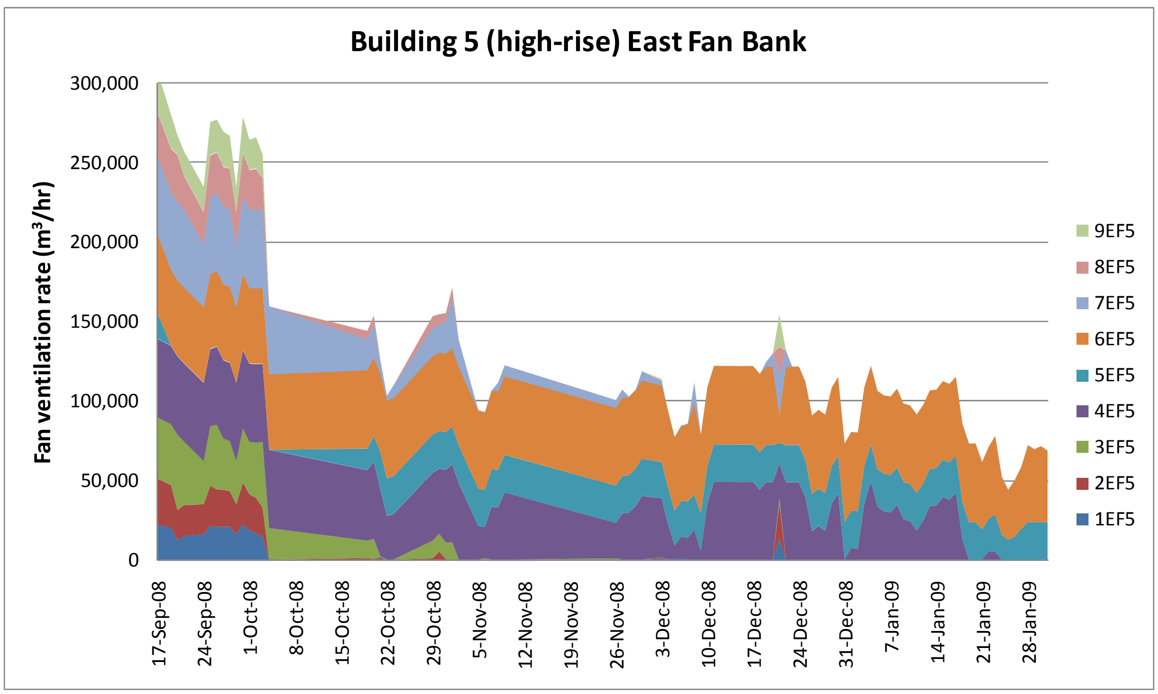

Figure 31. Average daily (based on hourly average) ventilation rates of the east fan bank of Building 5 (high-rise) showing the individual fan contributions.

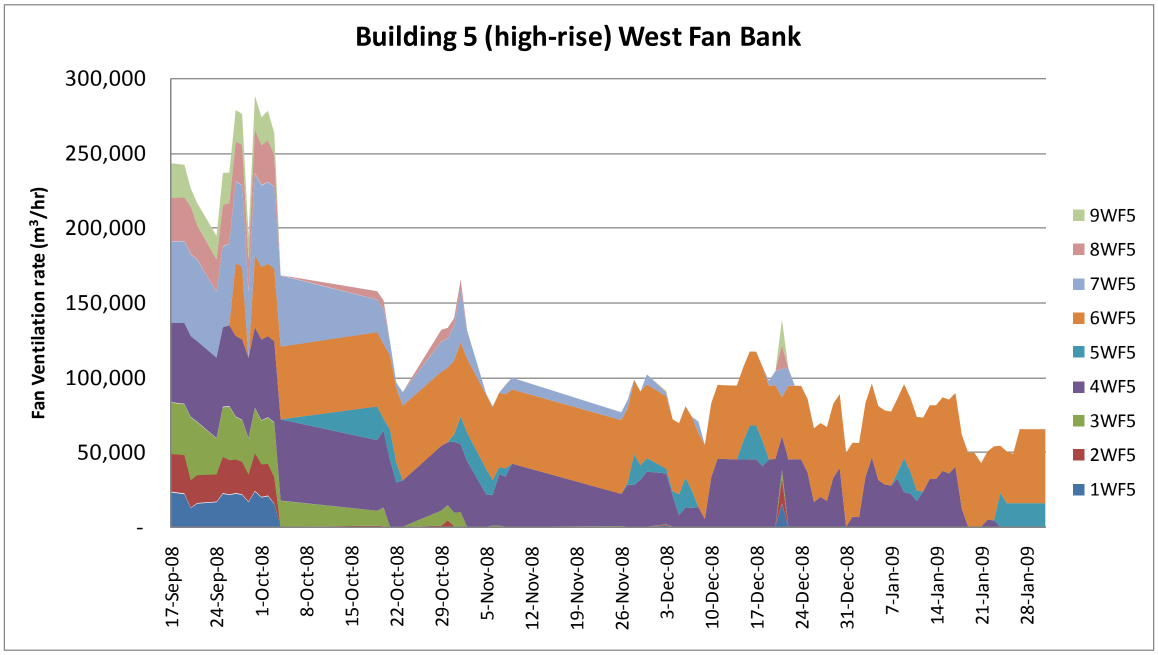

Figure 32. Average daily (based on hourly average) ventilation rates of the west fan bank of Building 5 (high-rise) showing the individual fan contributions.

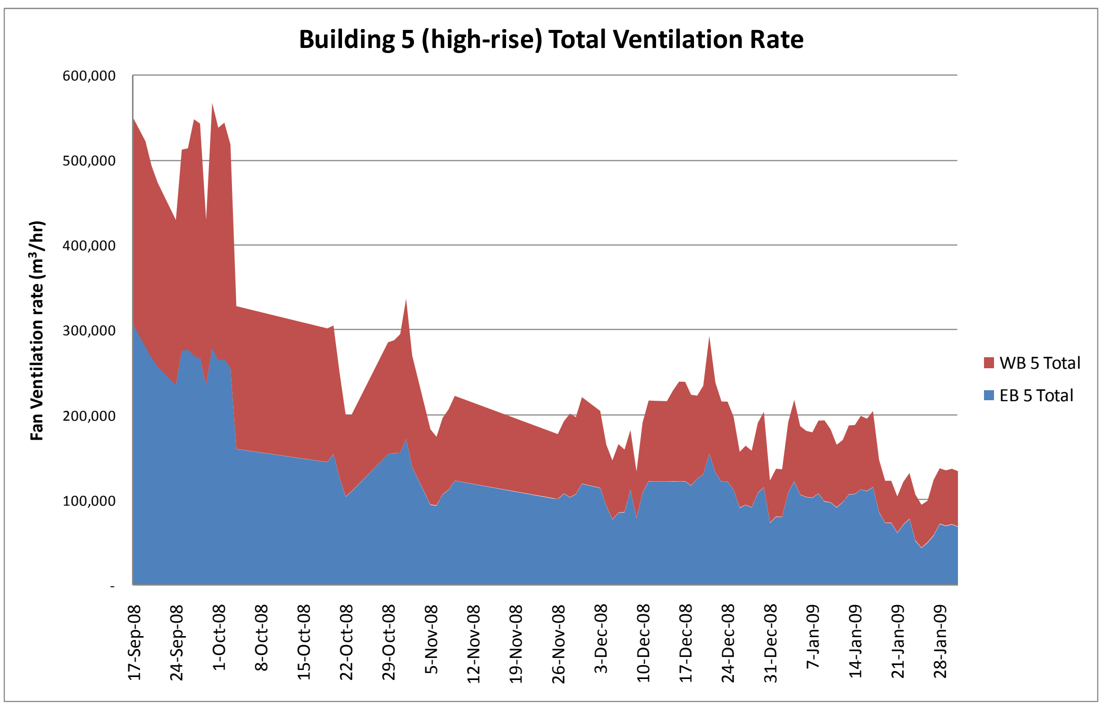

Figure 33. Average daily total daily ventilation rate for Building 5 (high-rise) showing the summed contribution from each fan bank.

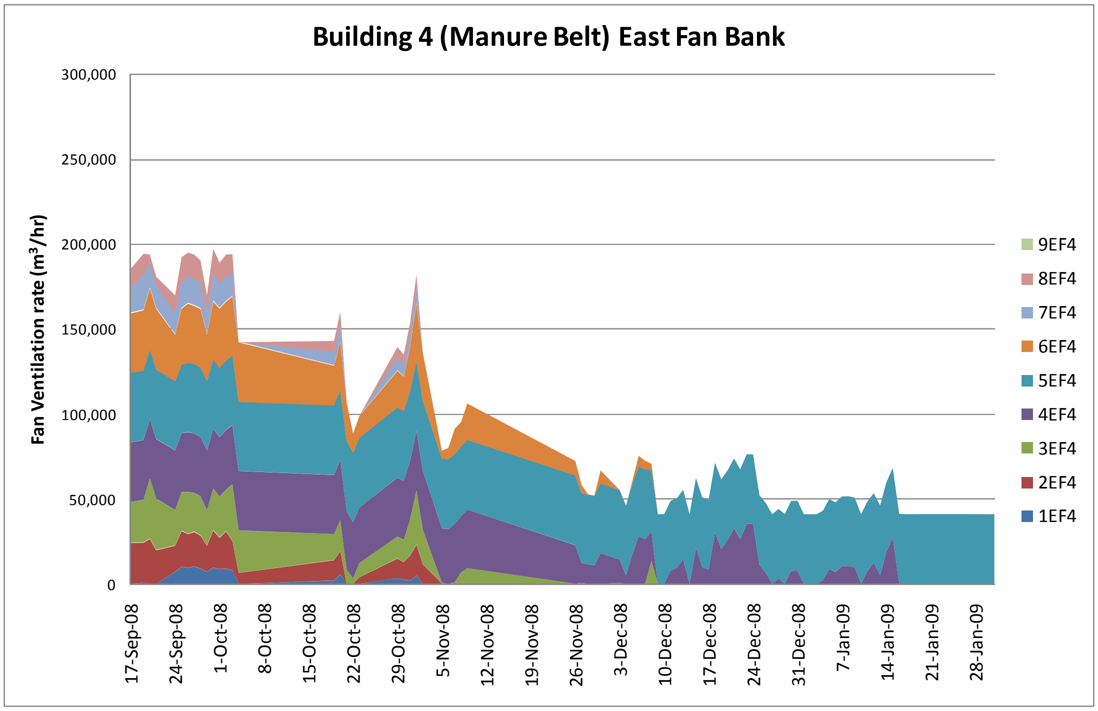

Figure 34. Average daily (based on hourly average) ventilation rates of the east fan bank of Building 4 (manure-belt) showing the individual fan contributions.

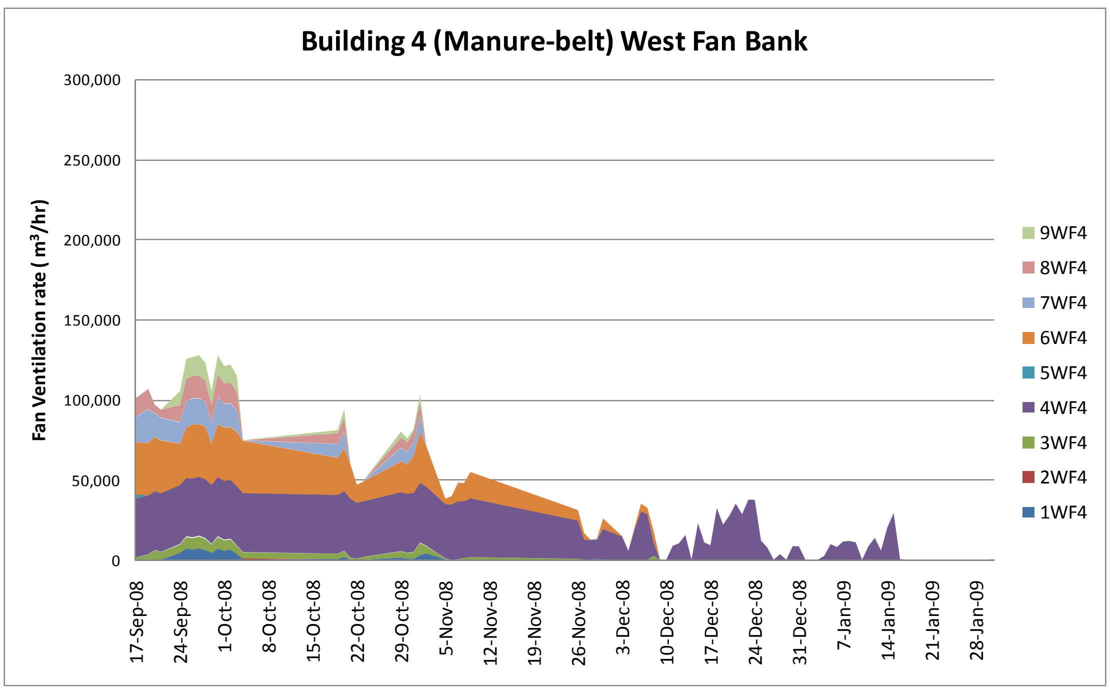

Figure 35. Average daily (based on hourly average) ventilation rates of the west fan bank of Building 4 (manure-belt) showing the individual fan contributions.

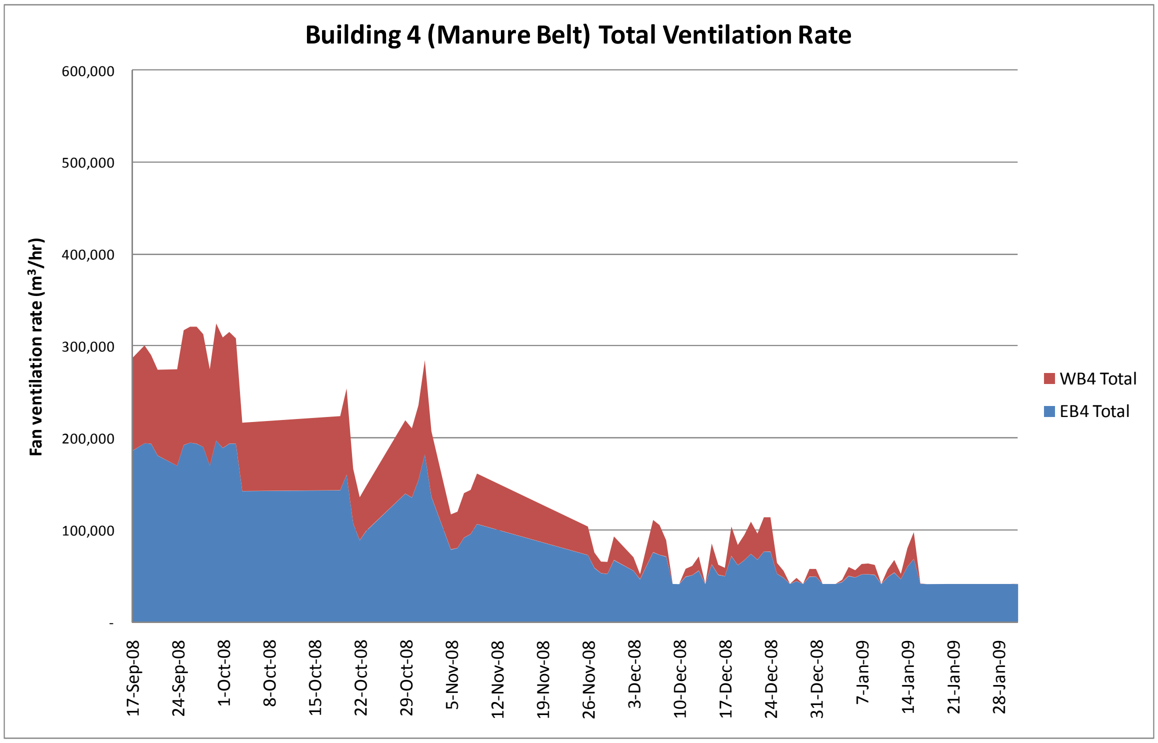

Figure 36. Average daily total daily ventilation rate for Building 4 (manure-belt) showing the summed contribution from each fan bank.

Ammonia Concentrations and Emission Rates

Figure 37 shows a sample 24-hour record of NH_3 concentration as measured by the INNOVA 1412 analyzer and the custom-built valving system for September 17, 2008. The concentrations measured typically ranged from 0.97 to 2.10 ppm, with a mean of 1.48 ppm, in the exhaust air from the manure-belt barn and 5.31 to 15.47 ppm, with a mean of 11.62 ppm, in the exhaust air from the high-rise barn. As can also be seen, the background ambient air over the same period averaged 0.89 ppm. During the sampling period, the concentrations of ammonia observed from Building 5 (high-rise) were typically higher than the concentrations from the Building 4 (manure-belt). This was likely due to the different management techniques. The manure stays longer in the high-rise building than in the manure-belt building, where the manure is regularly transported to a storage manure barn. Also, a higher degree of variability was observed in the high-rise (Building 5) NH_3 concentrations when compared to that of the manure-belt (Building 4), and this trend was observed consistently throughout the period of sampling as is demonstrated by examining a randomly selected day from the other sampling months (see Figure 38; October 6, 2008).

Figure 39 shows the overall values and variations between Building 5 (high-rise) and Building 4 (manure-belt) for several months over the sampling period and shows that the high-rise ammonia concentration was consistently higher than that of the manure-belt building. The data between July 2008 and September 2008 were test data for individual poultry building analysis, and the gaps in the August and September months were due to instrument failure, which required the 1412 to be returned to the manufacturer for repair.

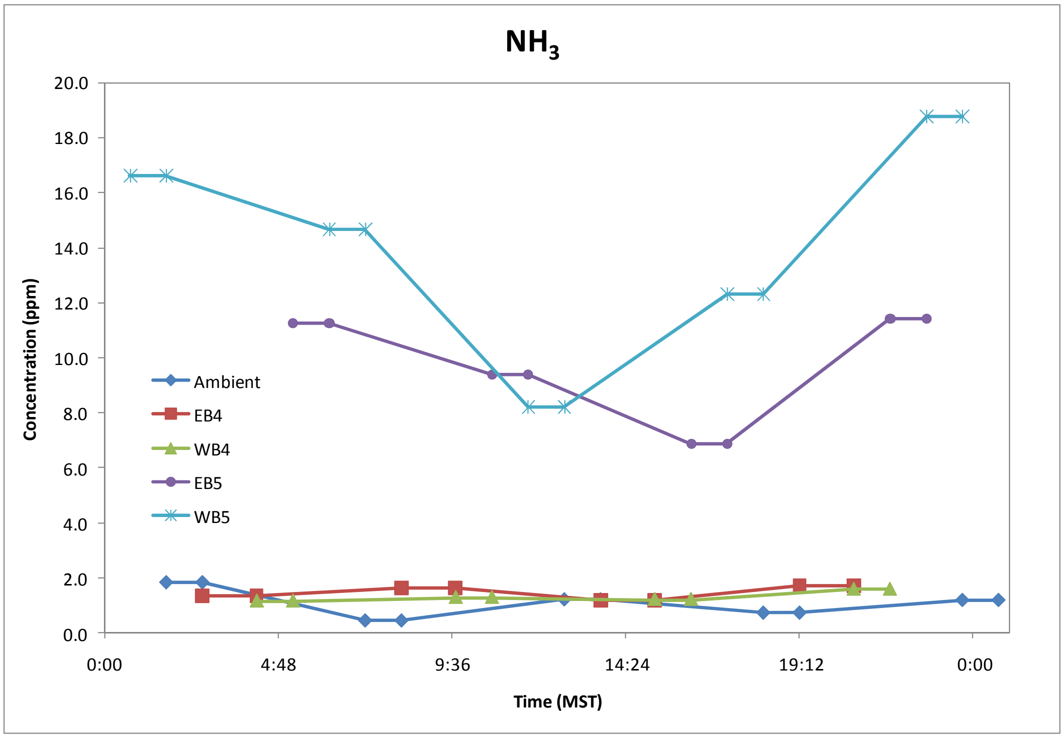

Figure 37. Diurnal gaseous NH_3 concentration (09/06/08).

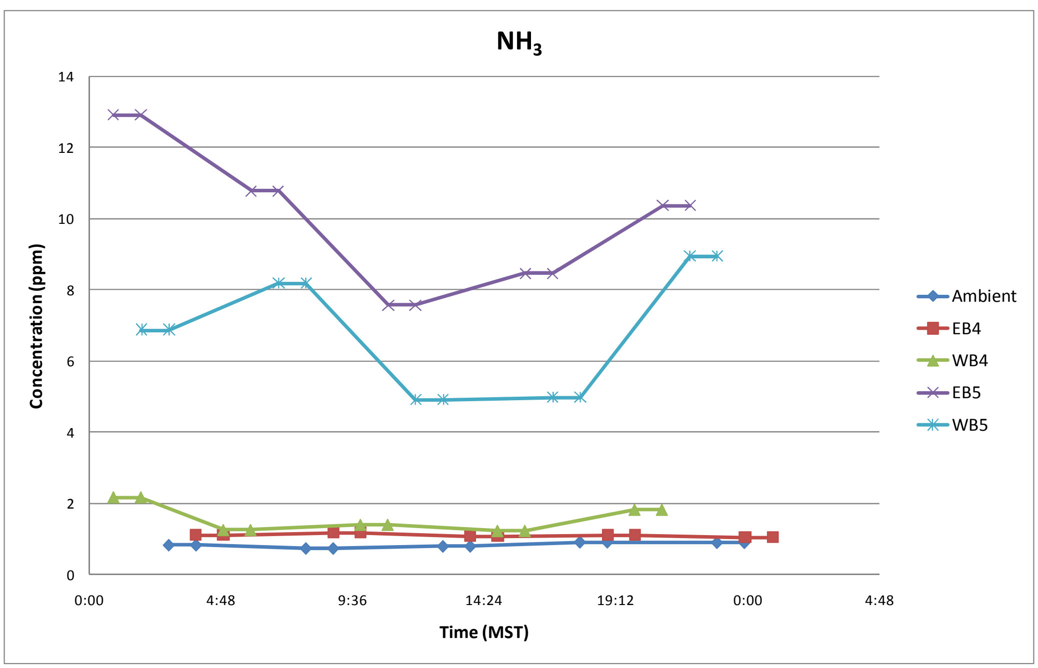

Figure 38. Diurnal gaseous NH_3 concentration (10/06/08).

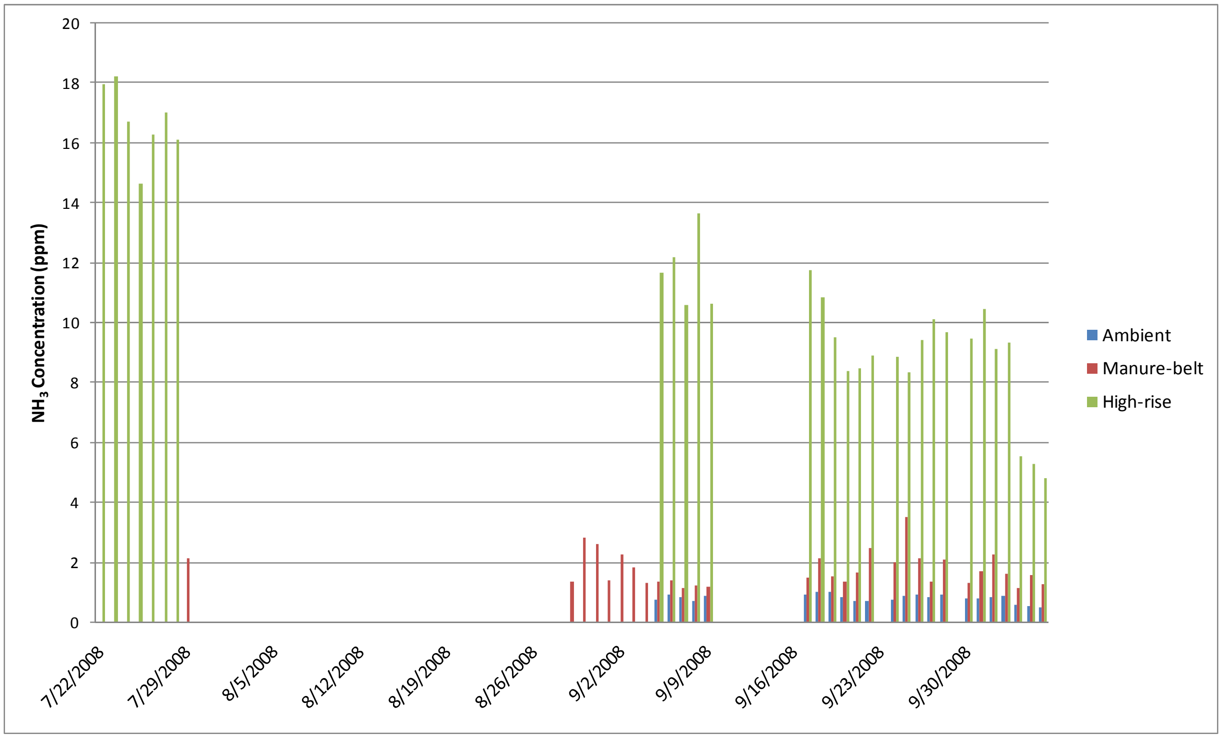

Figure 39. Diurnal gaseous NH_3 concentrations for July through September 2008.

As an example, Figures 40 and 41 show the relationships between the ventilation rates and the ammonia emission factors for both the manure-belt barn (Building 4) and the high-rise barn (Building 5), respectively, between September and October, 2008. Based on the plots, there is no strong evidence to suggest that an increase in ventilation rate leads to increased ammonia emission factor for the manure-belt building because the measured NH_3 concentration remained relatively constant. However, there seems to be a strong correlation pattern for the high-rise building, which suggests that an increase in ventilation rate leads to an increase in removal of NH_3 from the poultry building. Referring to Figure 41 (high-rise), the ammonia emission factor generally increased with the ventilation rate. However, there remained considerable variability in NH_3 emissions, even when the ventilation reached its maximum at around 400,000 m^3 hr^{-1}. This suggests two possibilities: (1) either a very high level of the manure exists at the ground floor of the poultry building such that the total building ventilation system cannot effectively renew the interior air or (2) the higher inside building temperature caused an increase in the emissions of ammonia from the manure. Review of the temperature profiles of the two building systems (Figure 26) and the total ventilation graphs (Figures 33 and 36) reveals that the high building temperatures did not occur at the same time as the highest ventilation rates. Therefore, it is most likely that the maximum NH_3 rates were a function not only of the higher ventilation rates, but also of the amount of manure in the basement holding area.

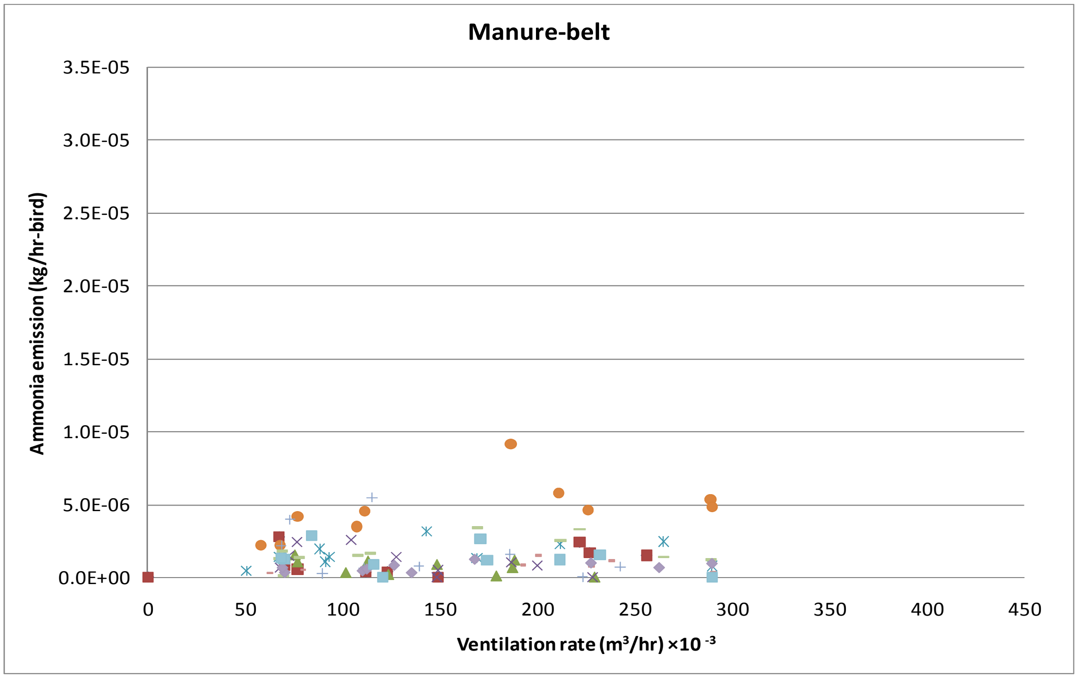

Figure 40. Ventilation rates vs. NH_3 emission factors for manure-belt building (sampling period of September and October 2008).

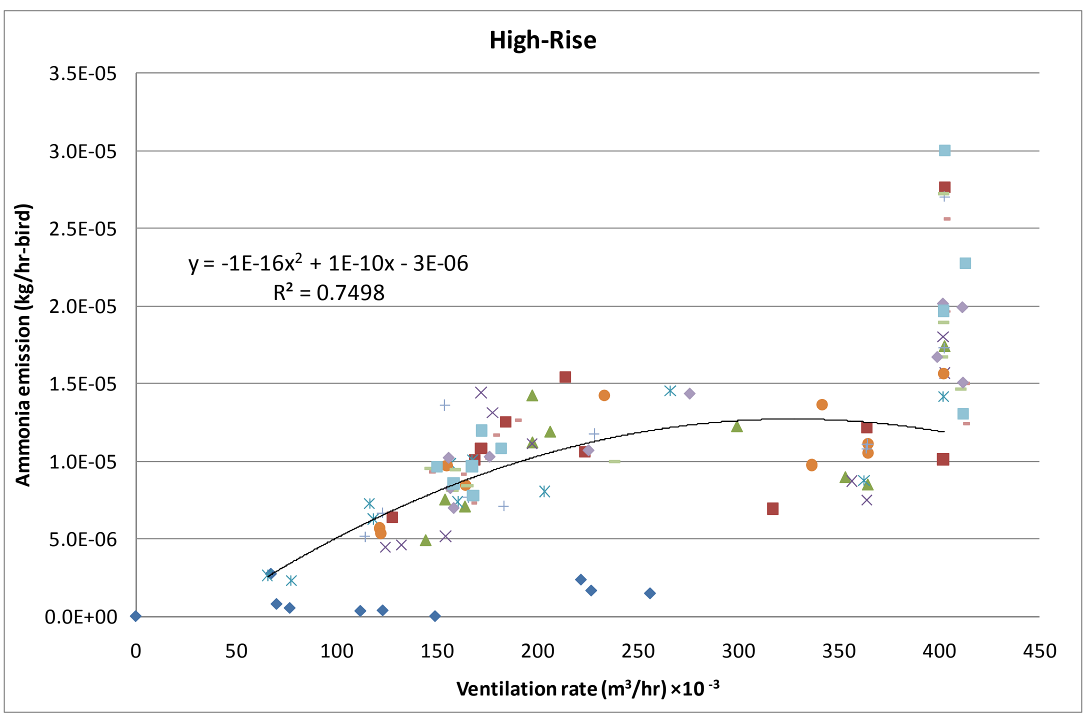

Figure 41. Ventilation rates vs. NH_3 emission factors for high-rise building (sampling period of September and October 2008).

Figure 42 shows the average daily pattern for NH_3 emissions for the poultry management techniques sampled during this study. There was a conspicuous difference between the average daily emission rates for the two management techniques. The NH_3 emission factor was consistently and significantly higher in the high-rise building throughout the sampling period. Over the fall sampling period, the NH_3 emission factors ranged from 0.09 lbs yr^{-1} $bird^{-1}$ to 0.28 lb yr^{-1} $bird^{-1}$, with a mean of 0.22 ± 0.07 lbs yr^{-1} $bird^{-1}$ (313 ± 87.0 mg $bird^{-1}$ day^{-1}) for the high-rise barn (Building 5), with the uncertainty representing one standard deviation. For the manure-belt barn (Building 4), the NH_3 emission factors ranged from 0.01 lb yr^{-1} $bird^{-1}$ to 0.09 lb yr^{-1} $bird^{-1}$, with a mean of 0.03 ± 0.02 lbs yr^{-1} $bird^{-1}$ (37.2 ± 24.9 mg $bird^{-1}$ day^{-1}). The ammonia emissions estimated in this study compare with the poultry ammonia emission factors stipulated by U.S.E.P.A. (2004) of 0.89 and 0.25 lbs yr^{-1} $bird^{-1}$ for wet and dry layers, respectively.

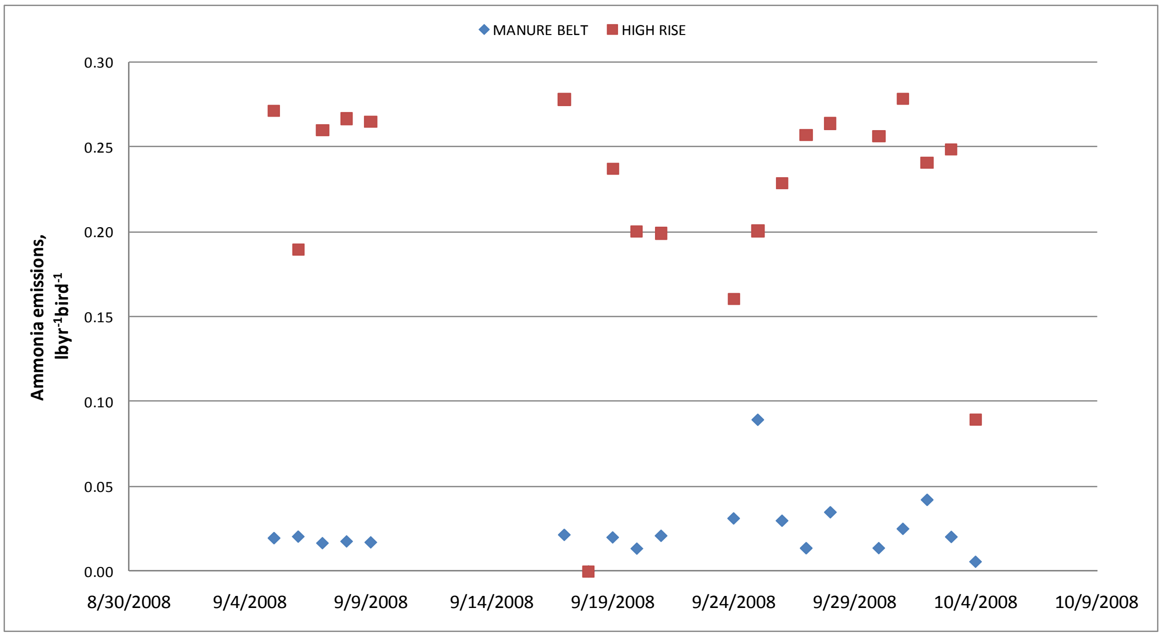

Figure 42. Daily average ammonia emission factors from manure-belt and high-rise management techniques.

Ethanol (C_2H_5OH or EtOH) Concentrations and Emission Rates

No significant average concentrations were registered for ethanol in either poultry building; the measured concentrations were consistently close to or below the minimum detection limits of the INNOVA 1412. Therefore, based on the generally insignificant results obtained, this study found ethanol emissions from the poultry buildings were negligible, regardless of the management techniques employed.

Nitrous Oxide (N_2O) Concentrations and Emission Rates

Similar to the behavior of NH_3 concentration in the high-rise building, the nitrous oxide (N_2O) concentrations in the high-rise barn (Building 5) showed a higher degree of variability than the concentrations observed in the manure-belt barn (Building 4). The N_2O concentrations from the high-rise barn were consistently higher than those from the manure-belt barn throughout the sampling period. For selected days, Figures 43 and 44 show these trends clearly. As with the ammonia, this is likely due to the longer duration of the manure in the high-rise barn as compared to the manure-belt barn. The N_2O average daily concentration for the specified monitoring period ranged from 0.39 ppm to 0.46 ppm, with an average of 0.43 ppm, for the manure-belt barn (Building 4) and 0.44 ppm to 1.59 ppm, with an average of 1.12 ppm, for the high-rise barn (Building 5).

However, little significant emission factors were derived for N_2O, which were consistently zero or close to zero, especially for the manure-belt building (see Figure 45). Also, the trend observed in the high-rise building where droppings accumulate for a long period of time before removal, corroborates the Intergovernmental Panel on Climate Change (IPCC) guidelines which suggests, for solid manure-based housing systems, an emission factor equal to 2% of the nitrogen is excreted by the animals (Smith et al., 2007). If the average NH_3 emissions from this study are assumed to be 98% of the total nitrogen emissions, the IPCC guidelines suggest potential N_2O emissions of approximately 0.0006 lbs bird^{-1} yr^{-1} (0.75 mg bird^{-1} day^{-1}) for the manure-belt barn and 0.00449 lbs bird^{-1} yr^{-1} (5.58 mg bird^{-1} day^{-1}) for the high-rise barn. These values are within the range of those shown in Figure 45.

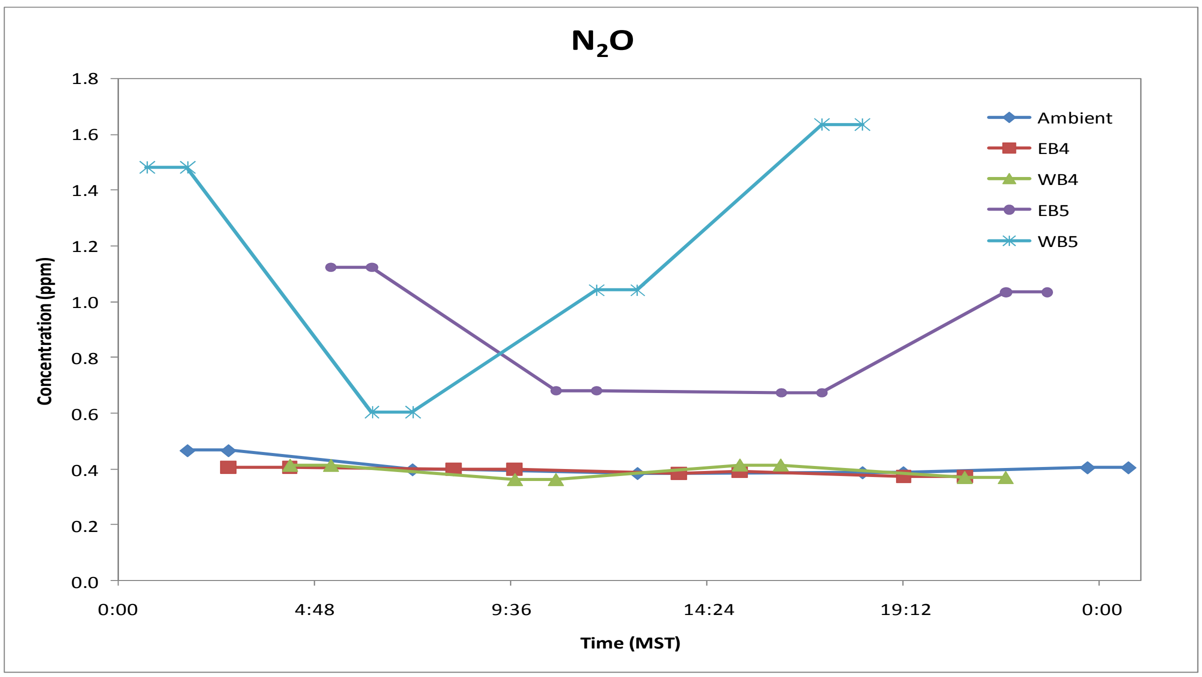

Figure 43. Diurnal gaseous N_2O concentration (09/06/08).

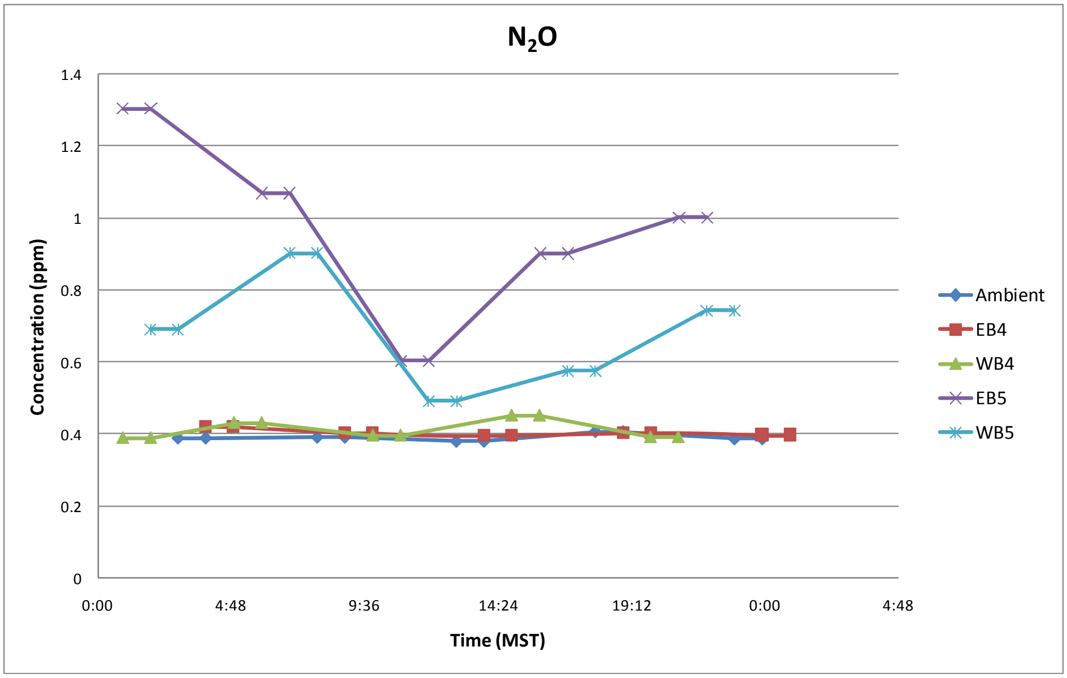

Figure 44. Diurnal gaseous N_2O concentration (10/06/08).

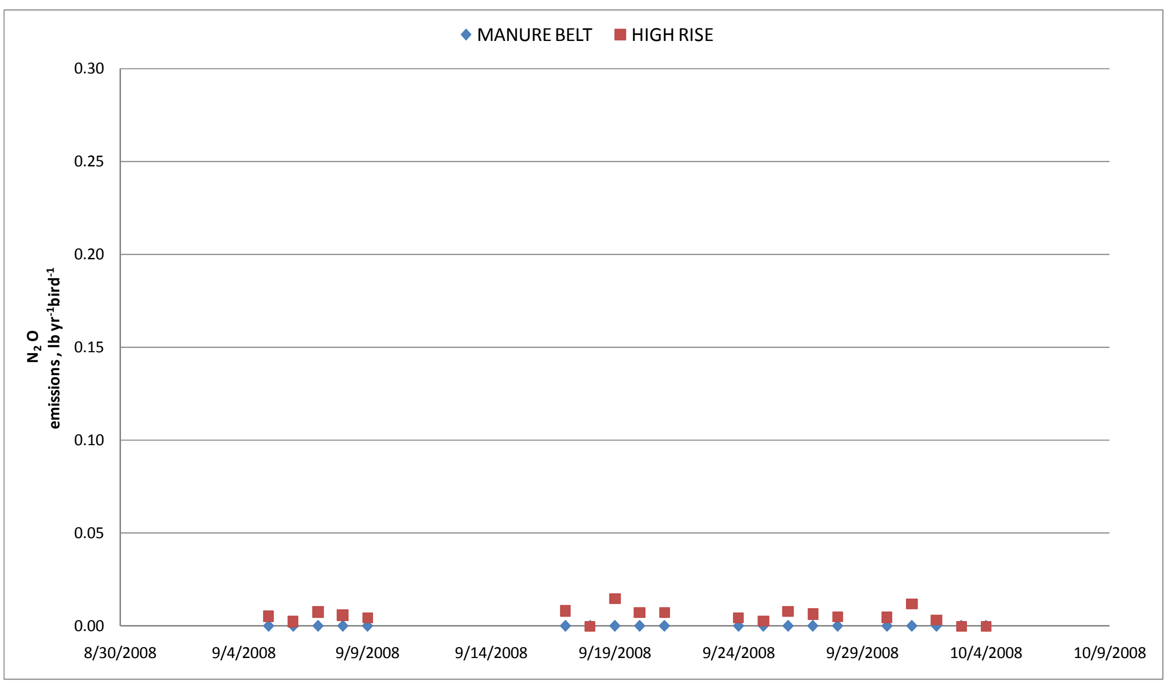

Figure 45. Daily average nitrous oxide emissions (N_2O) from the two different manure management techniques.

Hydrogen sulfide (H_2S) Concentrations and Emission Rates

Similar to ethanol and the nitrous oxide, no significant average concentrations were registered for H_2S in either poultry building; the measured concentrations were consistently close to or below the minimum detection limits. Therefore, based on the general insignificance of the results obtained, this study found the H_2S emission factor from the poultry buildings to be negligible, regardless of the management techniques employed.

Carbon Dioxide (CO_2) Concentrations and Emission Rates

The daily carbon dioxide (CO_2) concentrations exhibited diurnal variability in both the manure-belt and high-rise barns (Figure 46), much like the NH_3 concentrations (Figures 37 and 38), especially in the manure-belt building. However, unlike the other observed pollutants, the observed CO_2 concentrations were more similar between the two buildings, although the high-rise barn still showed an average CO_2 concentration nearly 50% higher than the manure-belt barn. A mean CO_2 concentration of 880 ppm, with a range of 511 ppm to 1,540 ppm, was recorded for the manure-belt building, while the high-rise building CO_2 concentrations ranged from 835 ppm to 1,621 ppm, with a mean of 1,256 ppm. This result was not unexpected as the CO_2 levels are not a function of the waste present but rather the animal population, animal activity, and the building ventilation rate. As presented in an earlier section (*Ventilation rates)*, the high-rise barn had an average ventilation rate of 2.02 m^3 hr^{-1} $bird^{-1}$ compared to a ventilation rate of 2.20 m^3 hr^{-1} $bird^{-1}$ for the manure-belt barn.

The CO_2 emission rates for the two poultry buildings tended to follow a similar pattern with slight differences during the early days of the sampling period as shown in Figure 47. The emission factors for the manure-belt building ranged from 61 lbs yr^{-1} $bird^{-1}$ to 109 lbs yr^{-1} $bird^{-1}$, with a mean of 84 lbs yr^{-1} $bird^{-1}$ (104.4 g $bird^{-1}$ day^{-1}), while the emission factors for the high-rise building ranged from 61 lb yr^{-1} $bird^{-1}$ to 94 lb yr^{-1} $bird^{-1}$, but with a mean of 84 lb yr^{-1} $bird^{-1}$ (104.4 g $bird^{-1}$ day^{-1}). Although the bird population in both houses differed (manure-belt average was 116,040 birds and high-rise average was 51,614 birds), this was not reflected in their CO_2 emission factors. This result demonstrates that the CO_2 production, per bird, in the two houses is roughly equivalent and suggests that the data collection and the emissions analyses protocols are reasonable and reliable and can be used to make informed inferences.

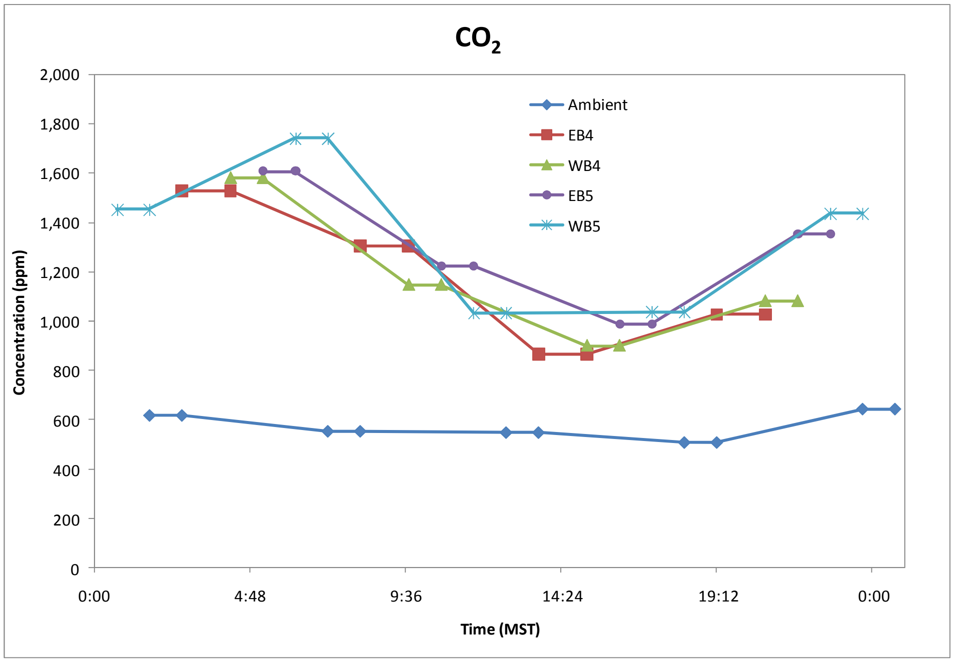

Figure 46. Diurnal gaseous CO_2 concentration (09/06/08).

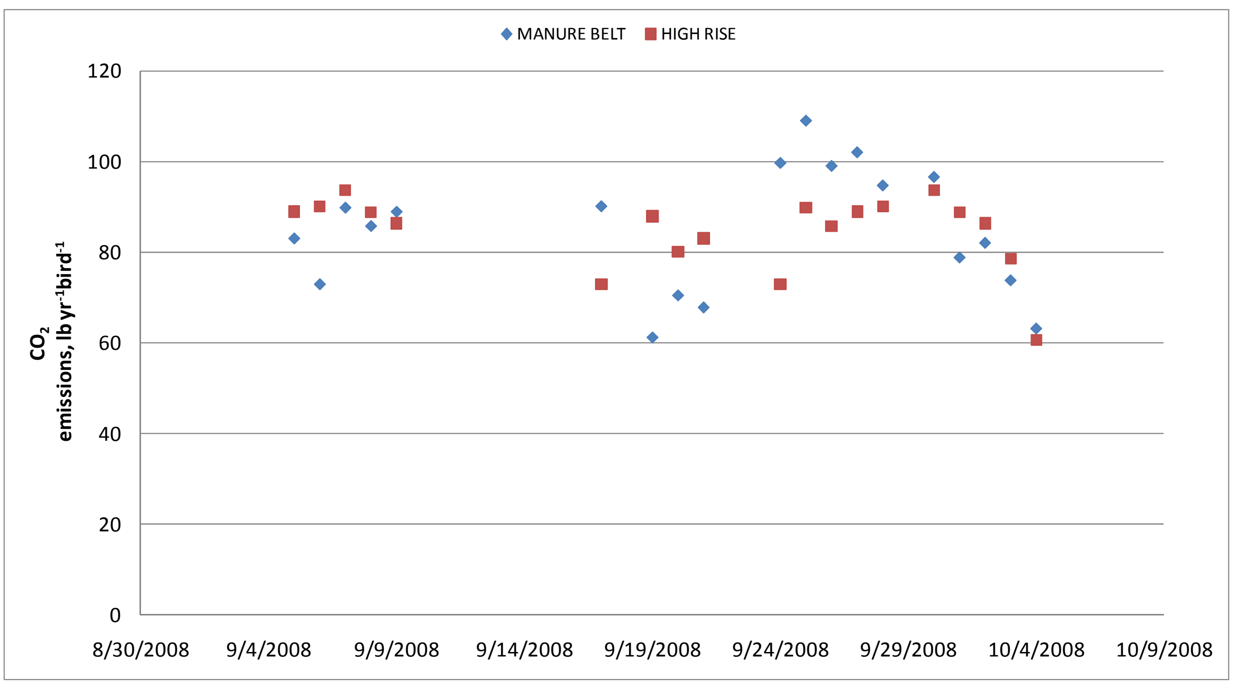

Figure 47. Daily average carbon-dioxide emission rates for the manure-belt and high-rise poultry buildings.

Particulate Matter (TSP, PM_{10}, $PM_{2.5}$, PM_1) Concentrations and Emission Rates

Building particulate fractionations, as measured inside the fan banks, are shown in Figures 48-51 for two successive typical sample days. It should be noted that the counts from the optical particle counters were converted to mass concentrations using previously discussed empirical algorithms. As might be expected from such a source, the larger-sized particle ranges strongly dominated, with almost no $PM_{2.5}$ and PM_1 observed. It is also of interest to note the sudden decrease in particle counts beginning around 10:00 am on both days shown (Sept. 17 and 18). By referring back to the ventilation rates for these same time periods (Figures 27 and 28), it can be seen that the decrease in particle concentrations is paralleled by sudden increases in building ventilation rates.

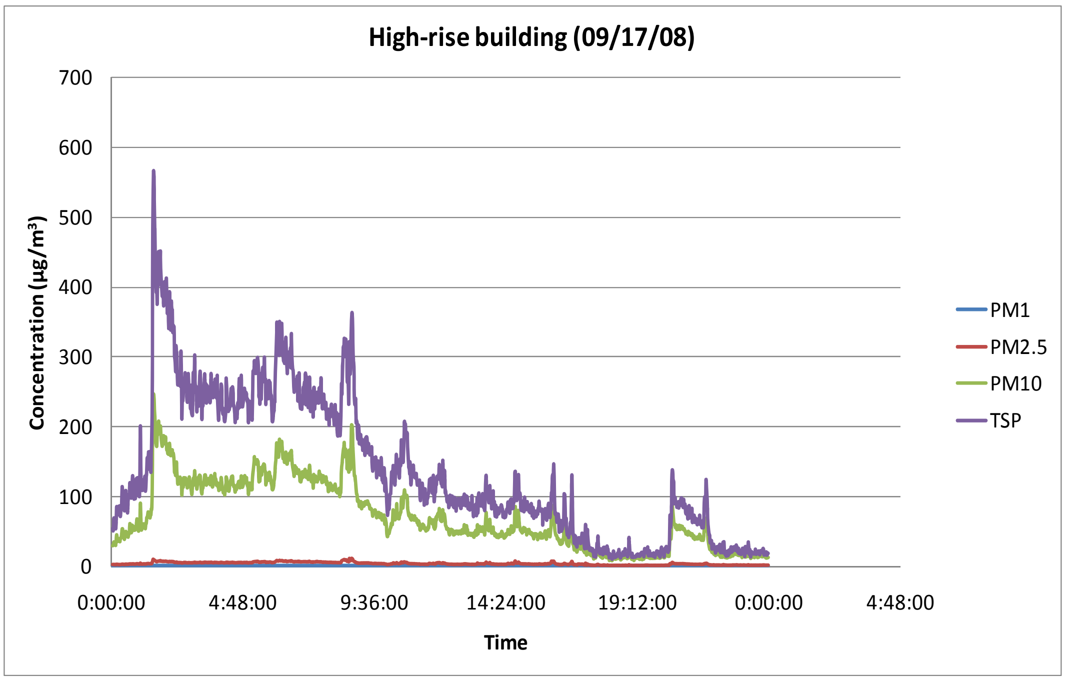

Figure 48. Time series trace of particulate matter inside high-rise building as measured by the optical particle counter (OPC), Sept. 17, 2008.

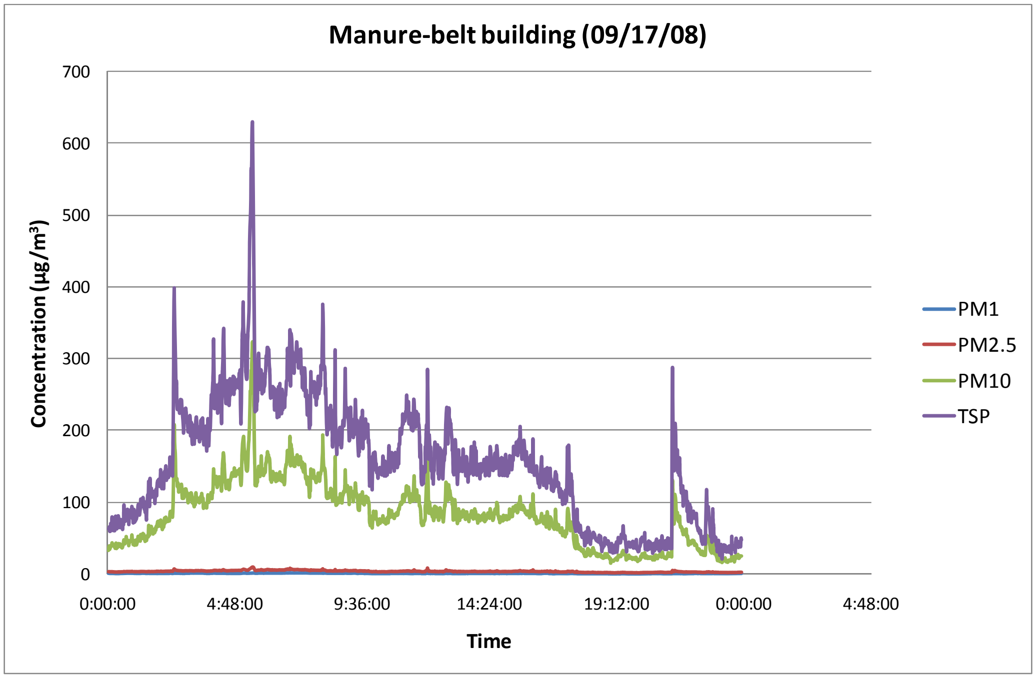

Figure 49. Time series trace of particulate matter inside manure-belt building as measured by the optical particle counter (OPC), Sept. 17, 2008.

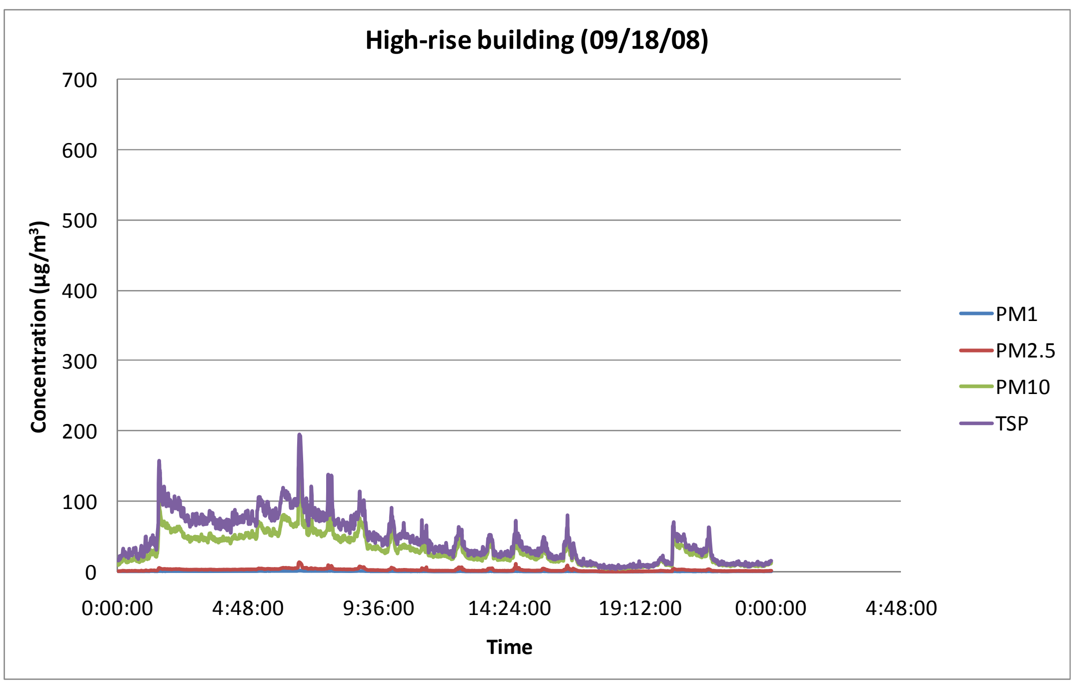

Figure 50. Time series trace of particulate matter inside high-rise building as measured by the optical particle counter (OPC), Sept. 18, 2008.

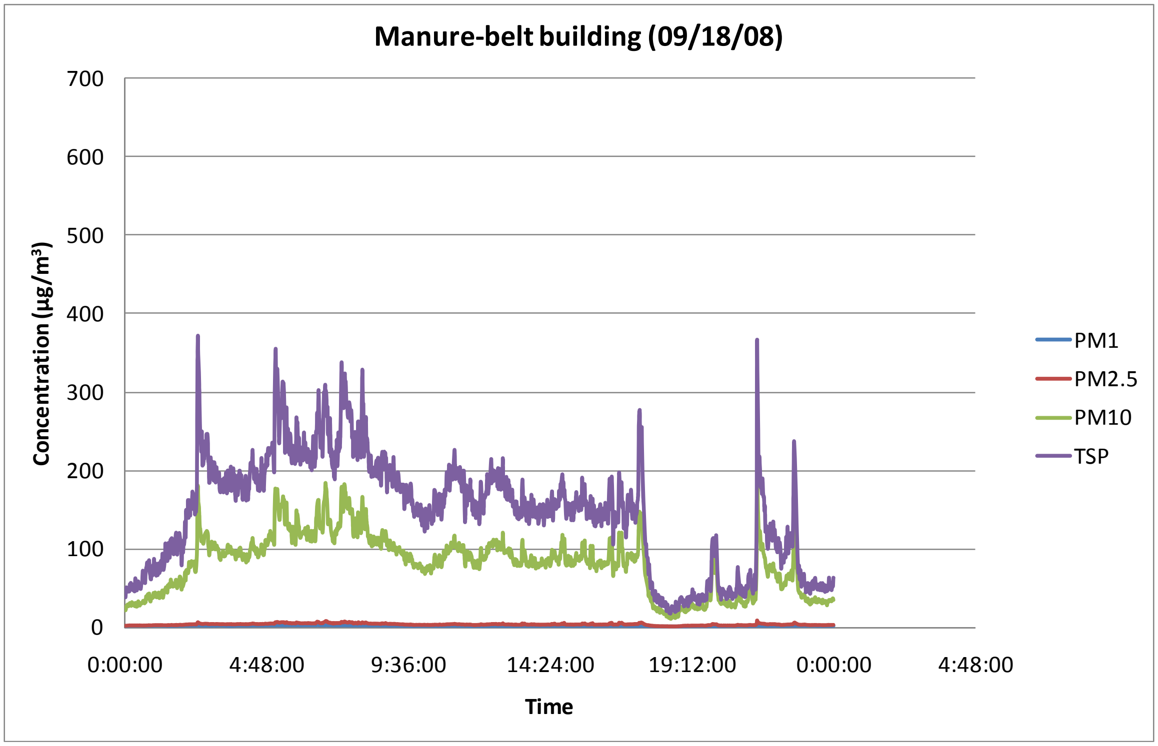

Figure 51. Time series trace of particulate matter inside manure-belt building as measured by the optical particle counter (OPC), Sept. 18, 2008.

Over the sampling period of September 17, 2008, the 24-hr mean TSP, PM_{10}, and $PM_{2.5}$ concentrations measured from the high-rise building were 137 ± 103 µg m^{-3}, 71 ± 49 µg m^{-3}, and 4.2 ± 2.1 µg m^{-3}, respectively. Similarly, the 24-hr mean TSP, PM_{10}, and $PM_{2.5}$ concentrations from the manure-belt building were 156 ± 88 µg m^{-3}, 83 ± 45 µg m^{-3}, and 3.7 ± 1.3 µg m^{-3}, respectively. Interestingly, for both manure management techniques, the PM_{10} concentrations were around 52% of the TSP values and the $PM_{2.5}$ concentrations were around 2.5% of the TSP values.

Over the next consecutive sampling period, September 18, 2008, the 24-hr mean TSP, PM_{10}, and $PM_{2.5}$ concentrations measured from the high-rise were 47 ± 32 µg m^{-3}, 33 ± 21 µg m^{-3}, and 3.3 ± 1.7 µg m^{-3}. Also, the measurements from the manure-belt were 147 ± 72 µg m^{-3}, 81 ± 37 µg m^{-3}, and 3.9 ± 1.2 µg m^{-3} for TSP, PM_{10} and $PM_{2.5}$, respectively. On this day, the particulate matter concentrations from the manure-belt were higher than those of the high-rise building, indicating the potential for day-to-day variability. Figures 52 and 53 show the average PM concentration values for the selected days. These figures further indicate that the PM concentrations were dominated by larger particles both inside and outside the poultry facility with very minimal concentration of $PM_{2.5}$, which is typical of particles found in poultry buildings.

As can also be seen in Figures 48 through 51, high concentrations of PM were recorded in both houses, particularly between 12:00 am to 5:00 am, and then tapered down as the day progressed. The causes of the early morning TSP and PM_{10} peaks are not known since animal activity, feeding, worker activity, and other process variables were not specifically monitored.

However, it is likely that worker activities, operation of the feed conveyor, and changes in building ventilation may have played a part in the early morning TSP PM_{10} peaks.

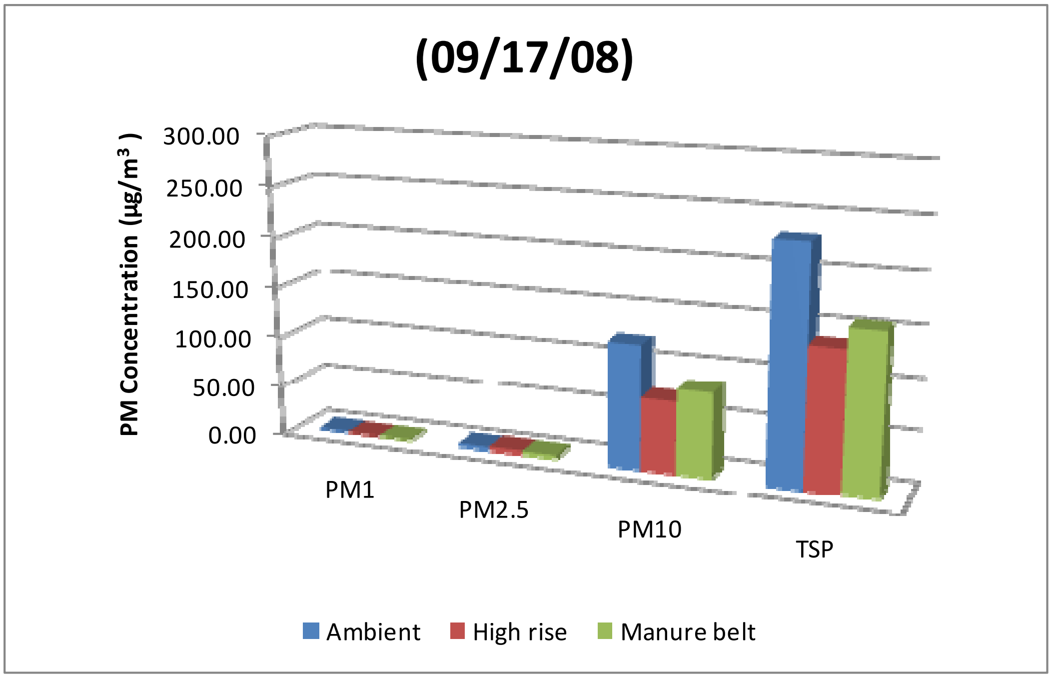

Figure 52. Derived average PM concentrations for the two manure management techniques and the ambient (outside) air, Sept. 17, 2008.

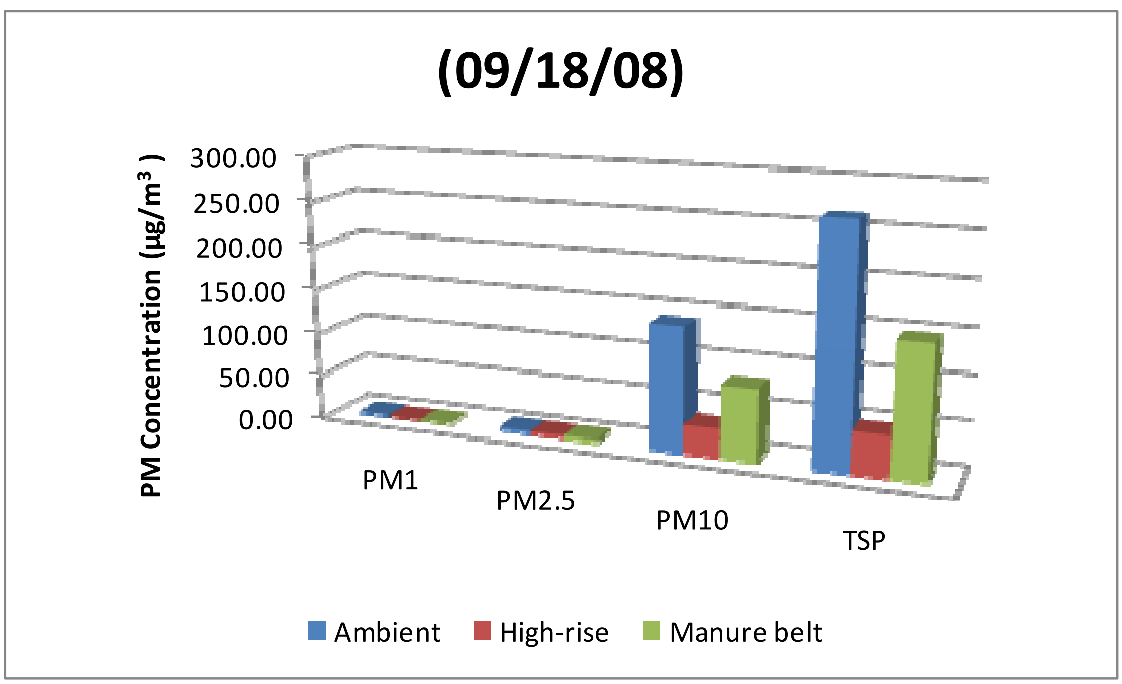

Figure 53. Derived average PM concentration for the two manure management techniques and the ambient (outside) air Sept. 18, 2008.

The PM_{10} and TSP measured from the manure-belt was higher than that from the high-rise building for sampling dates of September 17 and 18, 2008. Also, the ambient PM_{10} and TSP concentrations were higher than both the manure-belt and the high-rise because of the general facility activities (e.g. tractor movement) going on during those days. However, throughout the sampling period, the mean $PM_{2.5}$, PM_{10}, and TSP concentrations were 2.62±0.6 µg m^{-3}, 40±5 µg m^{-3}, and 92±13 µg m^{-3} for the high-rise building and 3.40±0.16 µg m^{-3}, 89±10.9 µg m^{-3}, and 195±31.9 µg m^{-3} for the manure-belt building; there was no sharp contrast between the buildings. Overall, the contributions of the $PM_{2.5}$ and PM_{10} towards the TSP in both buildings were 2.9% and 43% for the high-rise and 1.7% and 46% for the manure-belt. In general, the overall PM in the manure-belt building was slightly higher than that observed in the high-rise building. This was likely due to the higher number of birds in the manure-belt compared to the high-rise building

Furthermore, over the seasonal sampling period (see Figures 54-56), the PM_{10} and TSP concentrations from the high-rise building continued to drop until September 24, 2008 when a sharp spike was observed that was due to the manure clearing activities in the building, after which the decline continued. On the contrary, the PM concentration from the manure-belt stayed relatively constant over the sampling period as shown in Figures 55 and 56 for the month of September, 2008. Once again, very low $PM_{2.5}$ concentrations were recorded from the site as shown in Figure 54. The ambient concentration also fluctuated with facility activity throughout the sampling days as is prominently displayed in the TSP concentration (Figure 56).

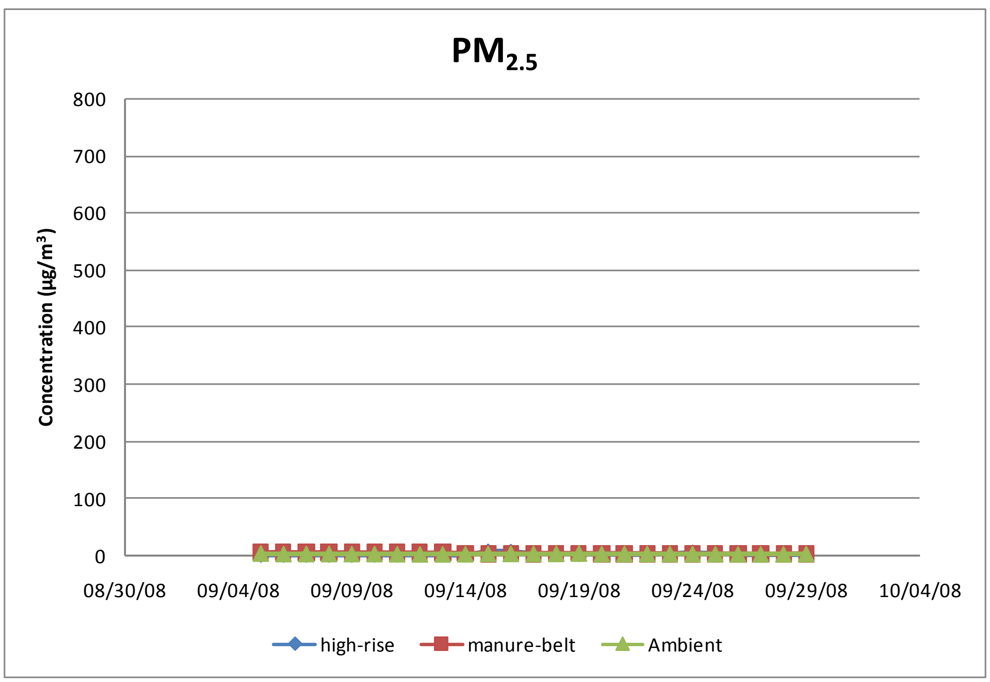

Figure 54. Comparison between the $PM_{2.5}$ concentrations for both management techniques and ambient (outside) air for Sept. 08.

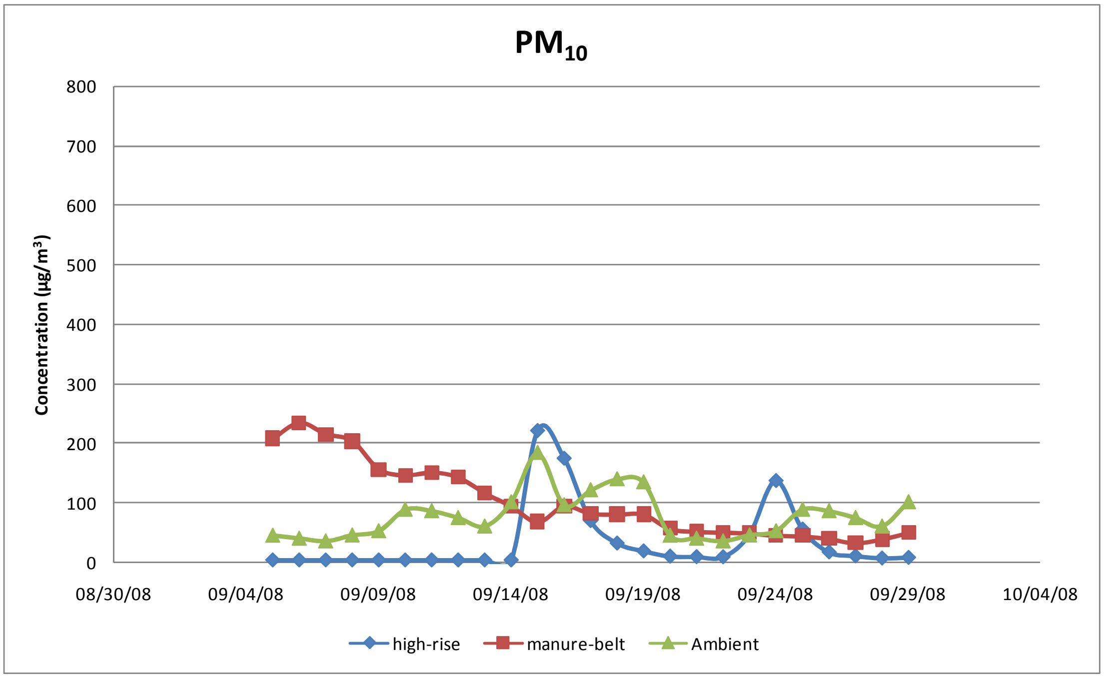

Figure 55. Comparison between the PM_{10} concentrations for both management techniques and ambient (ouside) air for Sept. 08.

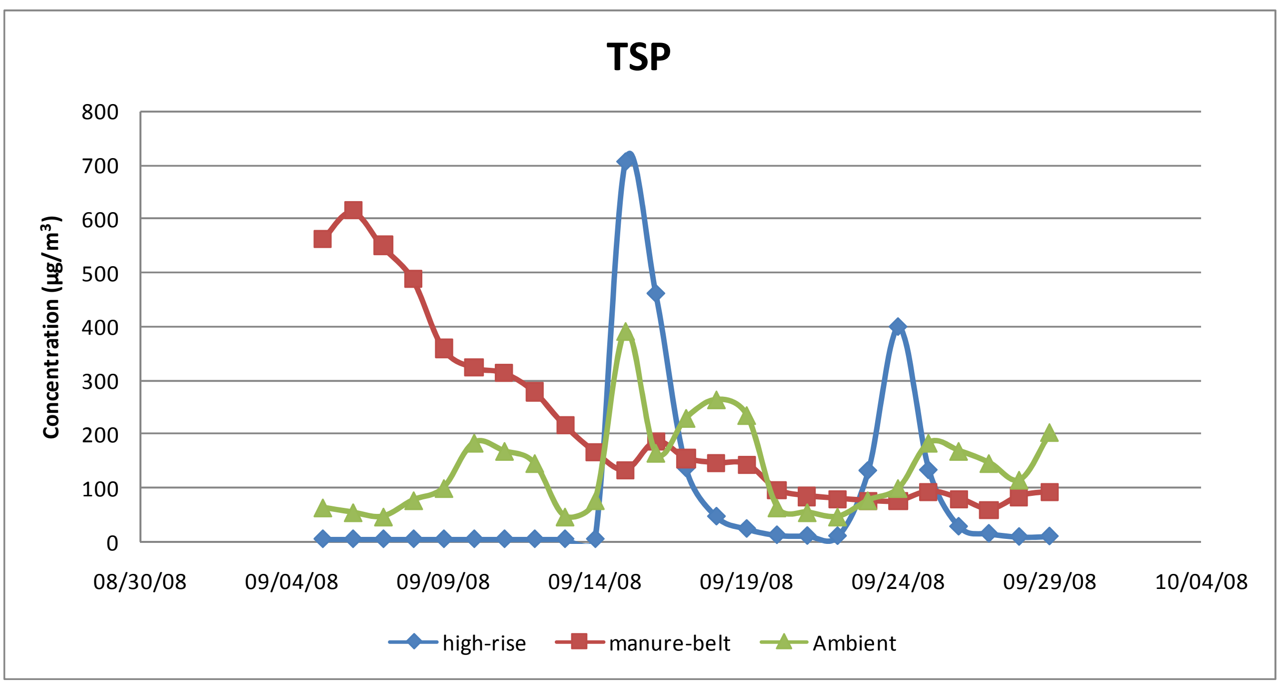

Figure 56. Comparison between the TSP concentrations for both management techniques and ambient (outside) air for Sept. 08.

Figures 57 and 58 show the relationship between the $PM_{2.5}$, PM_{10} and TSP concentrations for the month of September, 2008 for the high-rise and manure-belt building, respectively. Both plots also show the dominant TSP and PM_{10} contributions in both poultry buildings. Figures 59 and 60 show the monthly PM averages for both poultry buildings over the sampling period. More detailed data and plots can be found in Appendix C of Ogunlaja (2009).

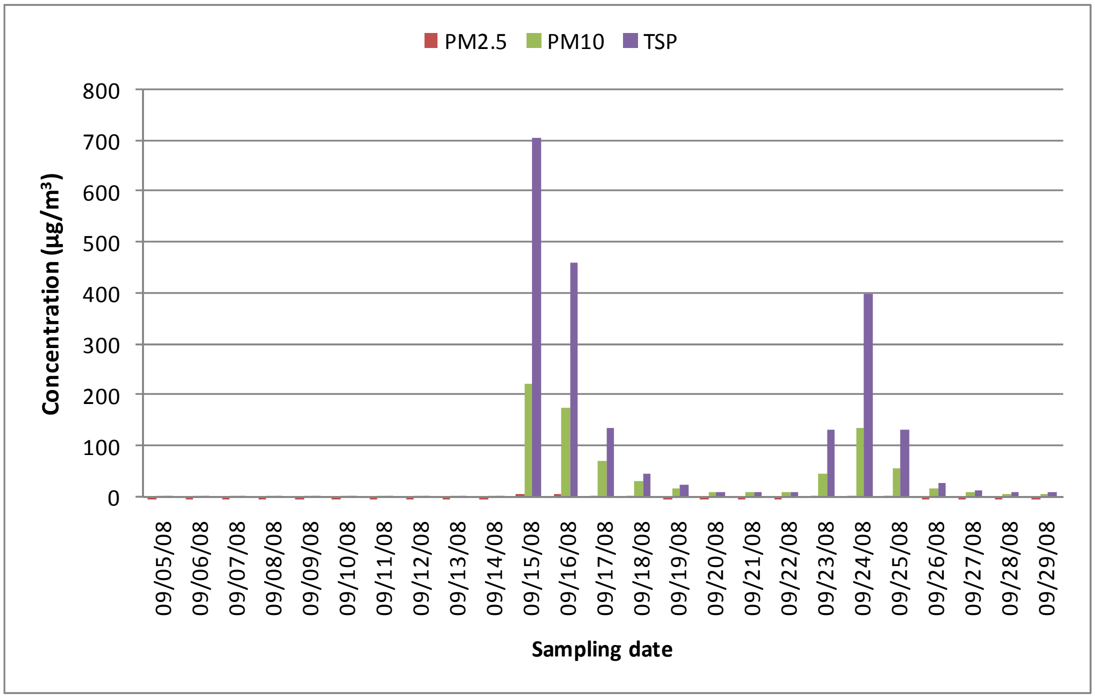

Figure 57. Particulate Matter concentration profile for the high-rise building for September 2008.

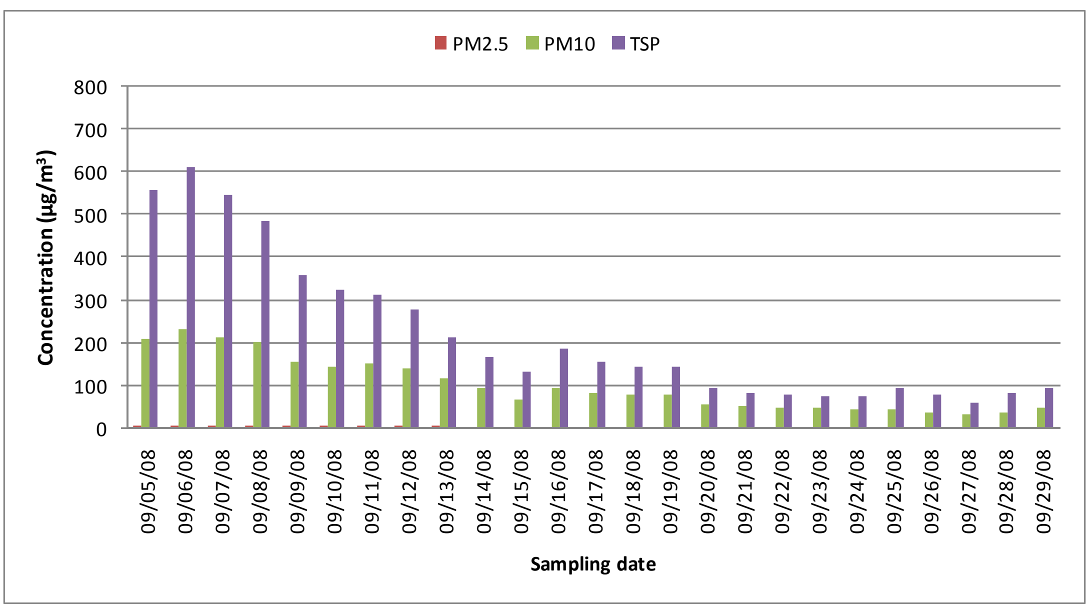

Figure 58. Particulate Matter concentration profile for the manure-belt building for September2008.

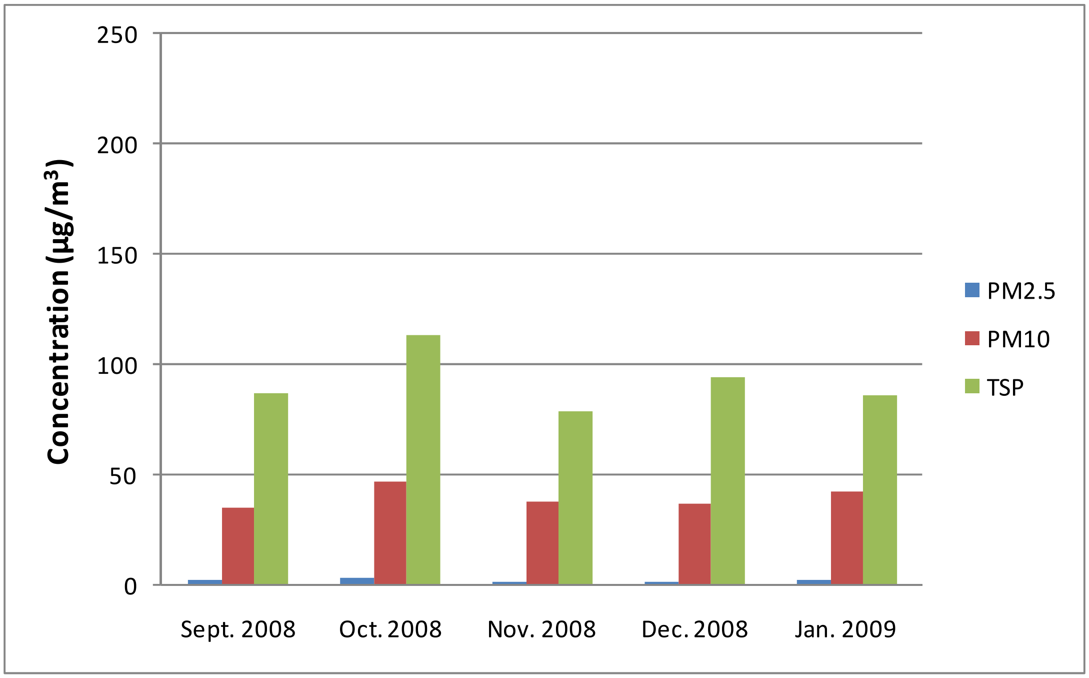

Figure 59. Monthly derived PM averages for the high-rise building over the sampling period.

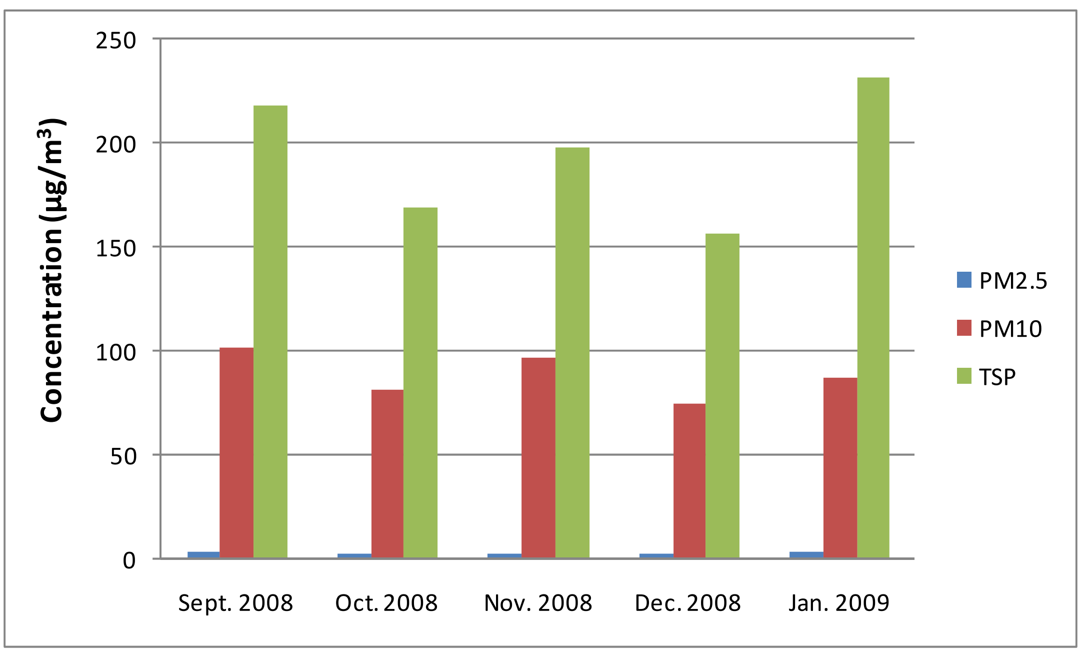

Figure 60. Monthly derived PM averages for the manure-belt building over the sampling period.

The derived daily (24-hr average) $PM_{2.5}$, PM_{10}, and TSP emission rates on September 18, 2008 were 42±19 g min^{-1}, 304±201 g min^{-1}, and 371±256 g min^{-1} for the high-rise, respectively, and 32±15 g min^{-1}, 633±570 g min^{-1}, and 832±452 g min^{-1} respectively, for the manure-belt building. The amplifying effects of ventilation on emissions can be observed by comparing PM concentration (Figure 61 and 62) with PM emission (Figure 63 and 64) over the sampling period of September 2008. These figures conspicuously show that the PM concentrations and emissions, on a mass per time basis, were higher for the manure-belt building than for the high-rise building, with the exception of a discrete period when the high-rise barn was being scraped of manure. As mentioned earlier, the higher particulate matter recorded from the manure-belt building was likely due to the higher number of birds in the building compared to the high-rise building; the vibration of the machines in conveying the manure from the building to the external storage building could also generate of more particulate matter than the high-rise building. Empirically, it was observed that when the belts were activated, a "shower" of particulate matter was released.

Over the 5-month sampling period, the average $PM_{2.5}$, PM_{10}, and TSP emission rates for the manure-belt building were 33±17 g min^{-1}, 821±316 g min^{-1}, and 1,691±775 g min^{-1}, respectively, and 28.4±10 g min^{-1}, 382±286 g min^{-1}, and 997±462 g min^{-1} for the high-rise building, respectively. Converting these emission rates into a per bird basis results in $PM_{2.5}$, PM_{10}, and TSP emissions of 0.41±0.21 g $bird^{-1}$ day^{-1}, 10.2±3.9 g $bird^{-1}$ day^{-1}, and 21.0±9.6 g $bird^{-1}$ day^{-1}, respectively, for the manure-belt barn and 0.79±0.28 g $bird^{-1}$ day^{-1}, 10.7±8.0 g $bird^{-1}$ day^{-1}, and 27.8±12. g $bird^{-1}$ day^{-1} for the high-rise barn, respectively. These data are shown graphically in Figure 65. As can be seen, the high-rise barn seems to have slightly higher TSP and PM10 emissions when normalized by bird numbers; however, the differences are insignificant at one standard deviation. The mean 24-hr live-mass specific emission rates for the different sampling dates over the sampling period may be found in Appendix C, Tables C-11 and C-12 of Ogunlaja (2009).

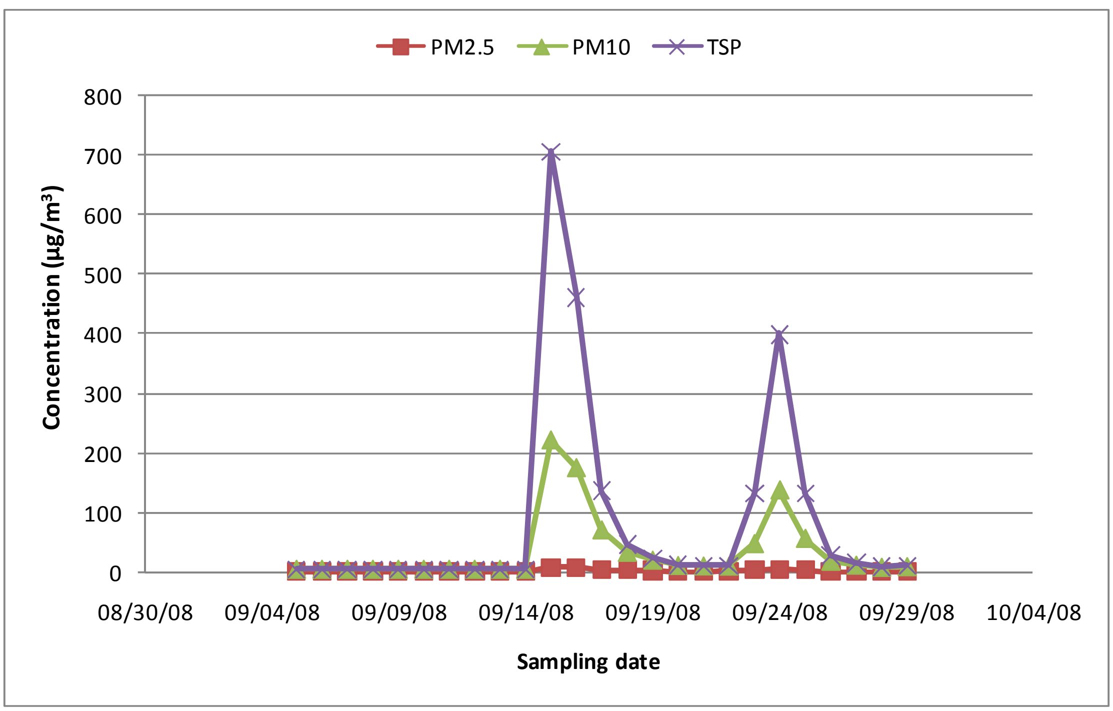

Figure 61. PM concentration profile for the high-rise building for Sept. 2008.

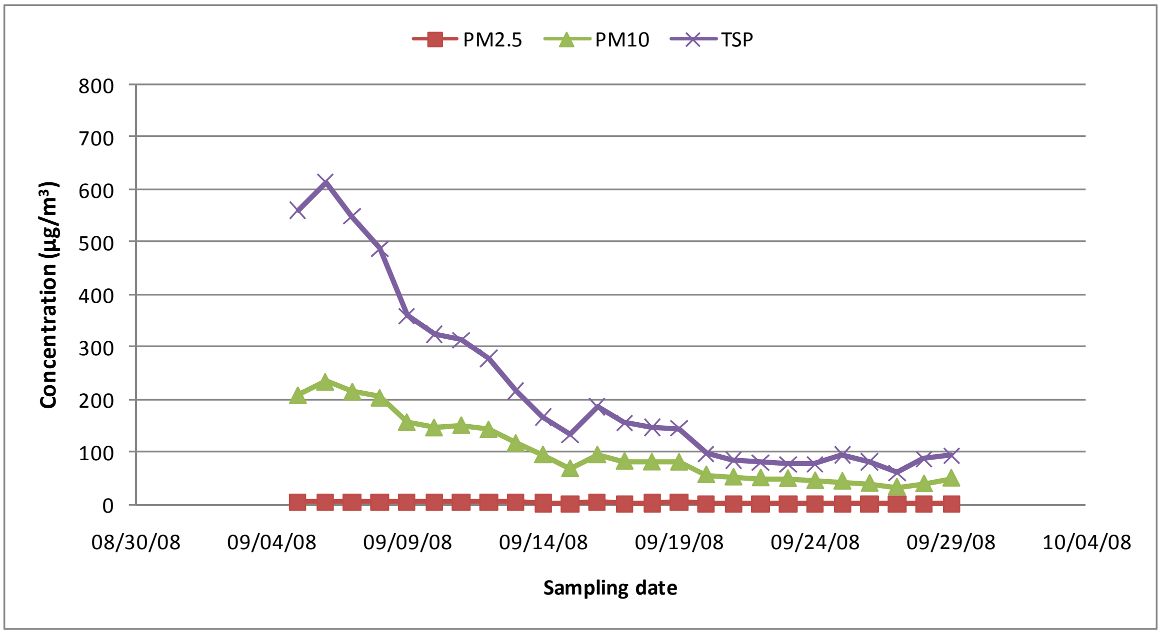

Figure 62. PM concentration profile for the manure-belt building for Sept. 2008.

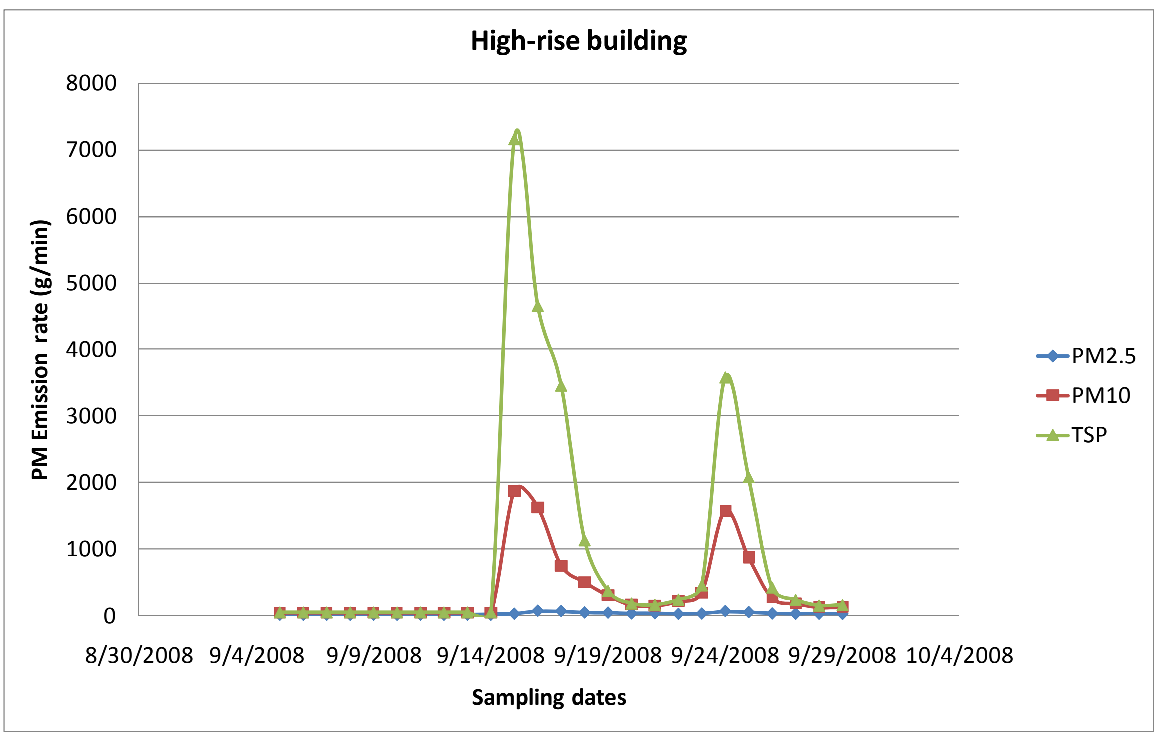

Figure 63. PM emission rate for the high-rise building for Sept. 2008.

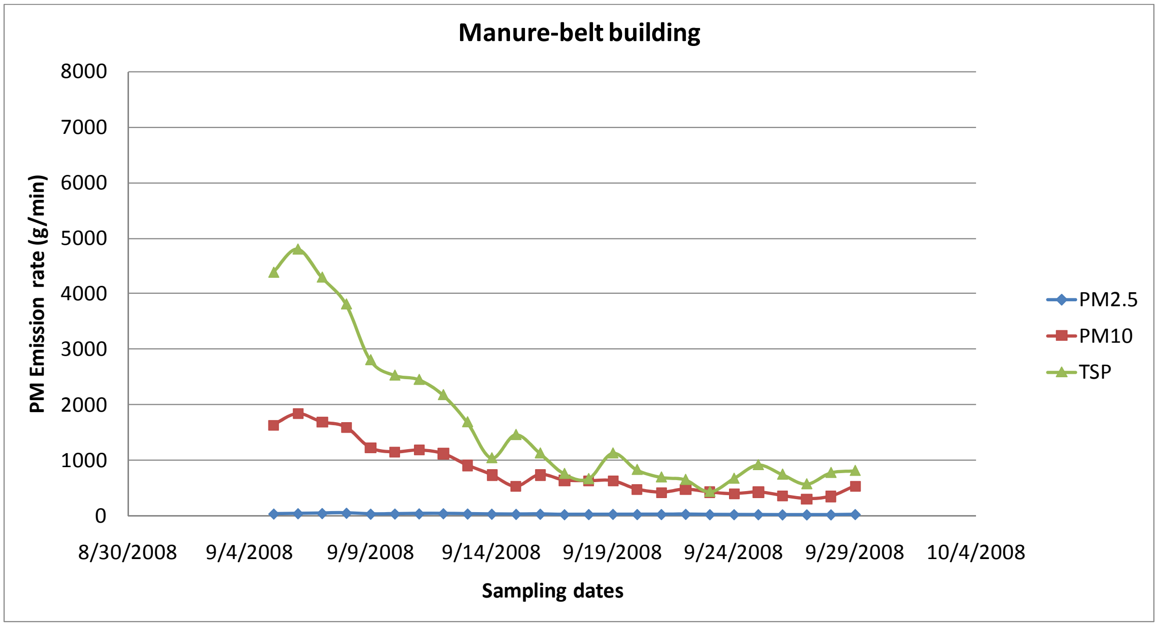

Figure 64. PM emission rate for the manure-belt building for Sept. 2008.

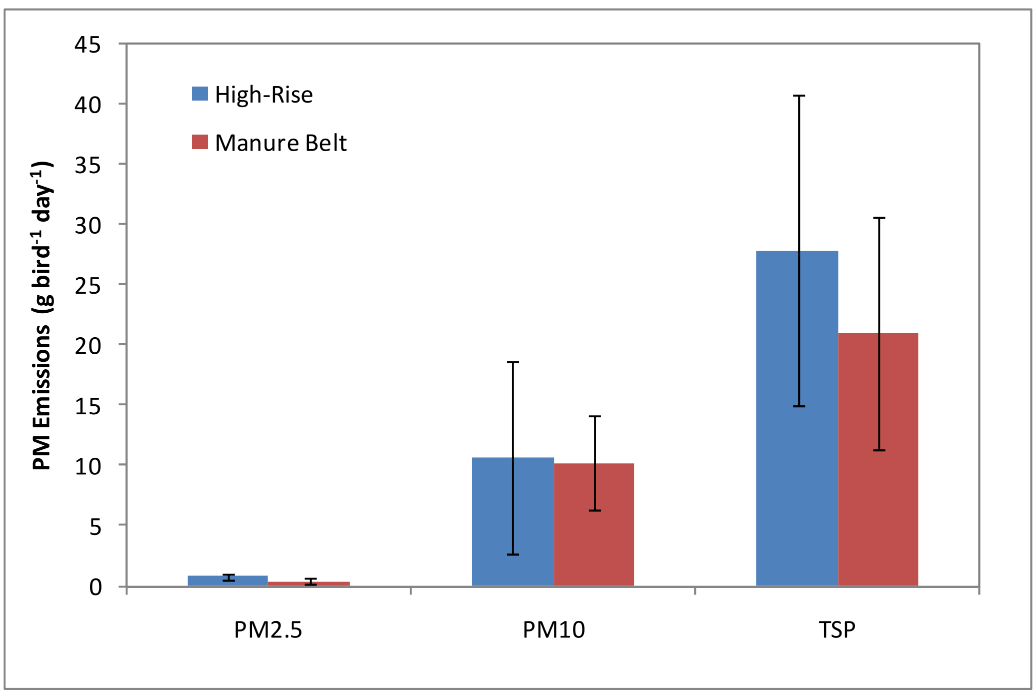

Figure 65. Seasonal PM emission rates for the high-rise manure-belt barns normalized by bird count.

Gas-phase Grab Samples (NH_3 and amines)

Using the IC method described previously, the ammonia in ambient air samples obtained at the target poultry facility was successfully detected and quantified. However, no organic amines were detected by the IC method in any of the collected samples. Figure 66 shows a representative chromatogram of a typical field sample (collected on 04/15/2009) that only showed a chromatographic peak for ammonia. The analyte retention time of this peak was 7.61 min.

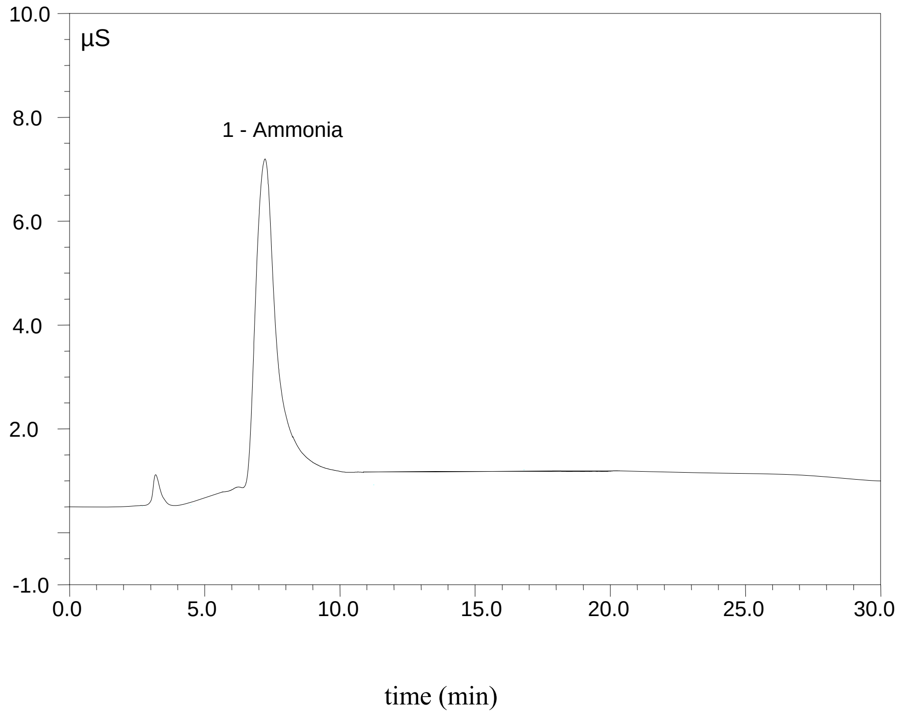

Figure 66. A chromatogram of a field sample (collected on 02/23/2009).

Exhaust Gas NH_3 Concentrations

The calculated NH_3 concentrations for the various samples that were taken are presented in Table 19 and 20. Results for samples collected each month from July 2008 to November 2009 are the average measurements of eight samples for each month. Table 19 shows the concentrations of ammonia detected in Building 5 (high-rise), and Table 20 shows the concentrations of ammonia detected in Building 4 (manure-belt). The uncertainties of each month are the standard deviations of total of four samples.

Table 19. Concentrations of ammonia from 07/2008 to 11/2009 at Building 5 (high-rise)

Month	**Concentration of NH_3 in the impinger solution (ppm)**	**Air Concentration of NH_3 in Building 5 (ppm) (not corrected for % recovery)**	**Air Concentration of NH_3 in Building 5 (ppm) (corrected for % recovery)**
Jul-08	30.1 ± 2.9	11.9 ± 2.3	13.4 ± 2.3
Aug-08	32.6 ± 2.4	13.7 ± 2.1	15.5 ± 2.1
Sep-08	29.3 ± 2.6	13.9 ± 2.0	15.7 ± 2.9
Oct-08	23.7 ± 3.6	13.2 ± 3.1	14.9 ± 3.1
Nov-08	23.9 ± 2.1	10.3 ± 2.4	11.6 ± 2.4
Dec-08	18.5 ± 2.2	8.4 ± 2.1	9.5 ± 2.1
Jan-09	17.3 ± 2.5	7.9 ± 2.1	8.8 ± 2.1
Feb-09	15.2 ± 2.4	6.5 ± 2.3	7.3 ± 2.3
Mar-09	16 ± 2.8	6.6 ± 2.1	7.4 ± 2.1
Apr-09	19.5 ± 1.8	9.7 ± 2.1	10.9 ± 2.1
May-09	21.6 ± 2.7	9.9 ± 2.2	11.2 ± 2.2
Jun-09	31.2 ± 3.8	13.8 ± 2.7	15.6 ± 2.7
Jul-09	29.1 ± 3.6	14.0 ± 2.9	15.8 ± 2.9
Aug-09	31.6 ± 3.6	14.6 ± 3.4	16.2 ± 3.4
Sep-09	27.1 ± 2.6	13.9 ± 2.2	15.7 ± 2.2
Oct-09	27.4 ± 3.8	10.7 ± 3.2	12.1 ± 3.2
Nov-09	19.7 ± 2.8	8.8 ± 2.9	9.9 ± 2.9
Minimum	15.2 ± 2.4	6.5 ± 2.3	7.3 ± 2.3
Maximum	31.6 ± 3.6	14.6 ± 3.4	16.2 ± 3.4
Average	24.7 ± 5.8	11.3 ± 3.5	12.7 ± 3.1

Table 20. Concentrations of ammonia from 07/2008 to 11/2009 at Building 4 (manure-belt)

Month	**Concentration of NH_3 in the impinger solution (ppm)**	**Air Concentration of NH_3 in Building 4 (ppm) (not corrected for recovery)**	**Original Air Concentration of NH_3 in Building (ppm) (corrected for % recovery)**
Jul-08	25.6 ± 3.6	10.2 ± 2.1	11.5 ± 2.1
Aug-08	28.5 ± 2.9	12.0 ± 2.4	13.5 ± 2.4
Sep-08	29.6 ± 2.5	14.0 ± 2.9	15.8 ± 2.9
Oct-08	24.6 ± 2.8	13.8 ± 2.5	15.6 ± 2.5
Nov-08	22.7 ± 3.2	9.7 ± 2.2	11 ± 2.2
Dec-08	19.8 ± 2.6	9.3 ± 2.1	10.2 ± 2.1
Jan-09	13.6 ± 2.8	6.1 ± 2.0	6.9 ± 2.0
Feb-09	15.2 ± 2.4	6.5 ± 1.8	7.3 ± 1.8
Mar-09	17.3 ± 2.1	7.1 ± 2.1	8 ± 2.1
Apr-09	18.2 ± 2.3	9.0 ± 2.4	10.2 ± 2.4
May-09	20.8 ± 2.8	9.5 ± 1.6	10.7 ± 1.6
Jun-09	30.7 ± 3.1	13.7 ± 2.3	15.5 ± 2.3
Jul-09	29.2 ± 3.3	13.8 ± 2.4	15.6 ± 2.4
Aug-09	25.6 ± 3.0	11.6 ± 3.1	13.1 ± 3.1
Sep-09	24.9 ± 2.4	12.7 ± 3.5	14.4 ± 3.5
Oct-09	25.6 ± 3.5	10.0 ± 3.4	11.3 ± 3.4
Nov-09	21.4 ±3.9	9.6 ± 2.9	10.8 ± 2.9
Minimum	13.6 ± 2.8	6.1 ± 2.0	6.9 ± 2.0
Maximum	30.7 ± 3.1	14.0 ± 2.9	15.8 ± 2.4
Average	23.2 ± 5.1	10.5. ± 3.2	11.9 ± 2.9

For high-rise barn (Building 5), the maximum concentration value of 16.2 ± 3.4 ppm of ammonia was detected in the month of August, and the minimum value of 7.3 ± 2.3 ppm occurred in February. The standard deviation was 5.8 ppm for concentrations in aqueous IC solutions and 3.1 ppm for concentrations in ambient air. For manure-belt (Building 4), the maximum concentration value of 15.8 ± 2.4 ppm of ammonia was detected in the month of September and the minimum value of 6.9 ± 2.0 ppm occurred in January. The standard deviation was 5.1 ppm for concentrations in aqueous solutions and 2.9 ppm for concentrations in ambient air. The yearly average of ammonia concentration was 11.9 ± 2.9 ppm for the manure-belt and 12.7 ± 3.1 ppm for the high-rise. The higher temperature in the warm months favors the volatility of ammonia, thus the higher ammonia concentration values in the summer.

On February 10th, 2009, the impinger samplers were set to sample air at east fan # 1 and west fan # 9 of Building 4 (the two ends of Building 4). The determined concentrations of ammonia were 6.9 ppm for east fan # 1 and 7.8 ppm for west fan # 9. On August 25th, 2009, the impinger samplers were set to sample air at the same fans (east fan # 1 and west fan # 9) of Building 4. The concentrations of ammonia were calculated at 12.9 ppm for east fan # 1 and 11.6 ppm for west fan # 9. The higher concentrations of ammonia in August compared to February at building 4 are likely due to the higher temperature during the summer, thus favoring the higher emission of ammonia. On February 24th, 2009, the impinger samplers were set to sample air at east fan # 1 and west fan # 9 of Building 5 (the two ends of Building 5). The determined concentrations of ammonia were 7.2 ppm for east fan # 1 and 6.1 ppm for west fan # 9. On July 21st, 2009, the impinger samplers were set to sample air at the same fans (east fan # 1 and west fan # 9) of Building 5. The concentrations of ammonia were calculated at 14.3 ppm for east fan # 1 and 13.7 ppm for west fan # 9. The higher concentrations of ammonia in July compared to February at Building 5 are once again likely due to the higher summer temperatures. Figure 67 graphically shows the monthly average values of NH_3 concentrations in the exhaust air for both Buildings.

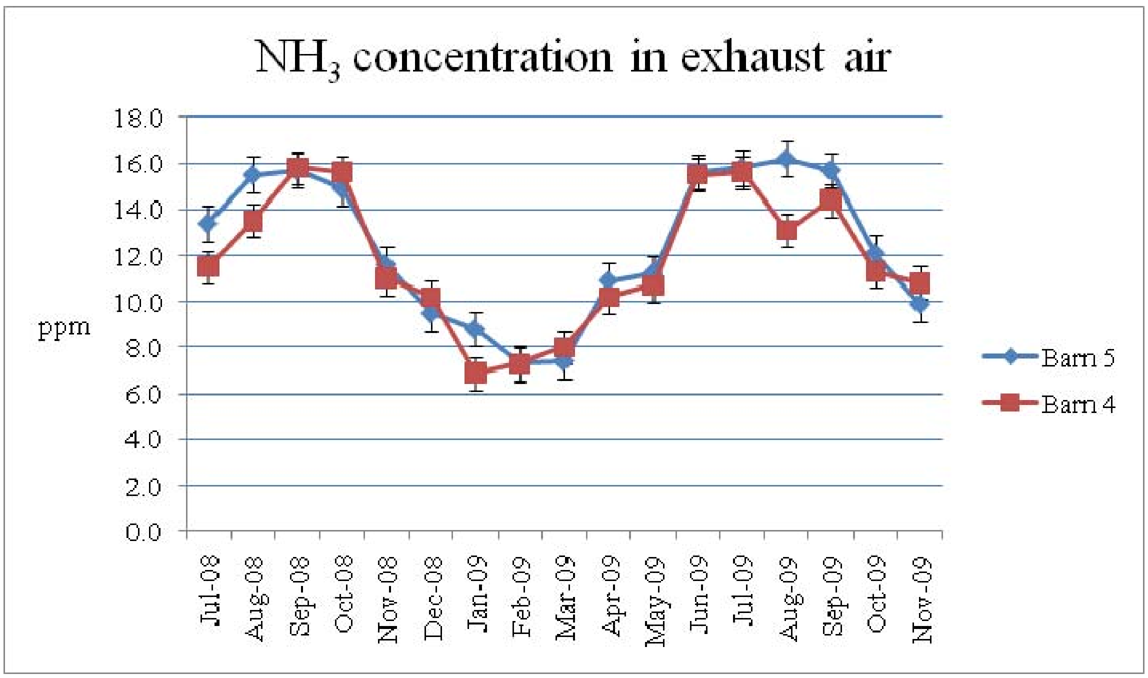

Figure 67. Ammonia concentrations in air detected by IC with standard deviations of 4 samples of each month.

Concentrations from the photoacoustic field gas monitor (Innova model 1412), which was used to measure the concentrations of ammonia gas at the same poultry facility, can be used to examine the validity of the IC grab sample measurements. Data recorded by the INNOVA 1412 on September 17th 2008, showed that the measured NH_3 gas concentrations typically ranged from 5.31 to 15.47 ppm over 24 hour period, with a mean concentration of 11.62 ± 0.89 ppm in the exhausted air from the high-rise building (Building 5) (refer to previous sections or Ogunlaja, 2009). Using the IC method (Table 19), the average concentration of NH_3 for the two hour measurements for the month of September was observed as 15.7 ± 2.9 ppm. In Ogunlaja's study (Ogunlaja, 2009), the yearly average concentration of ammonia measured by the photo acoustic field gas monitor was reported as 11.2 ± 0.75 ppm. Using the IC method in this study, the yearly ammonia concentrations ranged from 7.3 to 16.2 ppm, with a mean of 12.7 ± 3.1 ppm. Taking the uncertainties and differences in total sampling times into account, the two yearly average results were very similar in terms of the measured concentrations of ammonia in air. This suggests that the impinger sampling train method with the IC detection was comparable to the photo acoustic field gas monitor

The advantages of the photo acoustic field gas monitor were its simplicity and that it required no sample preparation. It provided real-time data and required no additional analysis time when compared to the IC method. It did not, however, differentiate between organic amines and NH_3, which was a major goal of the study. The IC method can also provide a validation of the photo acoustic field gas monitor measurements.

Validation of Amine Sampling

Because there were no amines detected by the IC method, another study was conducted to determine if the organic amines were not observed because they have too low a vapor pressure to be sampled efficiently by the impinger or because they are trapped as salts within the manure, or because they are of too low a concentration to be observed by the IC method. Alternately, they may simply not be present in the sample. To test these possibilities, a representative composite manure sample was generated by mixing four samples of manure sampled from October and November of 2009 (two samples of each month). The composite manure was used in the following experiments.

To test for the possibility that organic amines in the manure were tied up as low volatility salts within the manure, the pH of a composite manure sample was raised to approximately a pH of 9 by adding NaOH to the manure to convert any organic amines to the free bases. Approximately 20 grams of composite manure was placed into an Erlenmeyer flask, and the flask was connected with the impinger sampling train for air sampling. After 2 hours of air sampling, no organic amines were detected.

To test the possibility that organic amines had too low a vapor pressure to be effectively sampled by the impinger method, approximately 20 grams of the composite manure sample was placed into an Erlenmeyer flask and the Erlenmeyer flask was heated. A known volume of air was passed through the Erlenmeyer flask to transport any volatile amines to the impingers sampling train for trapping. The sample was run at room temperature and was heated up approximately to 30°C, 40°C and 50°C, respectively. Increasing the temperature of the samples would increase the volatility of any amine compounds present and would allow them to be trapped by the acid solution in the impingers. No organic amines were detected in the composite manure sample by increasing the sample's temperature.

To test the efficiency of trapping organic amines with the impingers and to study the actual detection limits of organic amines in the manure, the composite manure sample was spiked with known amounts of the standard amines and an impinger sampling train was set up to sample the room temperature air above the spiked manure sample. Approximately 20 grams of the composite manure sample that was spiked with 1 mL of standard amine was placed into an Erlenmeyer flask and the Erlenmeyer flask was connected into an impinger sampling train. Spiked concentrations of amine standards studied were: 40 ppm, 30 ppm, 20 ppm and 10 ppm. Results from the IC showed the impinger successfully trapped the higher levels of the amines when their concentration was above 20 ppm. The detection limit of the added amines to the manure sample was between 10 ppm and 20 ppm as no amine peaks were observed for the 10 ppm spiked sample.

A 30 ppm spiking solutions into the composite manure was approximately 1.5 ppm of pure organic amines (30 µg 20 g^{-1}). Using conductivity and peak areas from the chromatogram, the concentration of methylamine detected in the spiked manure sample was calculated at 9.4 ppm, which represents about 31% trapping efficiency (30 ppm spiked in vs. 9.4 ppm recovered). The calculated recovery concentrations for dimethylamine, trimethylamine, n-butylamine and triethylamine were 6.3 ppm, 4.9 ppm, 4.1 ppm and 2.4 ppm, respectively. The trapping efficiency for dimethylamine, trimethylamine, n-butylamine and triethylamine were 21%, 16%, 13% and 8%, respectively. This is consistent with the relative volatility of the amine standards. At the 10 ppm spiking level, no measureable amount of organic amines were seen. This would indicate that at lower concentrations, much of the organic amines, if present, are bound up in the manure sample and are not volatile. Based upon these spiking experiments, the organic amines in the manure must occur at a minimum concentration of 1 ppm (20µg 20g^{-1}) in order to have sufficient vapor pressure to allow enough to be transported to the impingers, trapped, and subsequently detected by the IC.

Emissions via Total Kjeldahl Nitrogen (TKN) and NH_3 for Nitrogen Balance

The TKN values of manure, feed and egg samples from manure barn, Building 4 (manure-belt), and Building 5 (high-rise) are shown in Table 21 and Table 22. The values reported were the average of four measurements from each month from May 2008 to November 2009, along with their standard deviations. The average calculated TKN values of manure from manure barn, Building 4, and Building 5 are reported in % N as 2.0% ± 0.3, 1.6% ± 0.3 and 1.9% ± 0.3, respectively. The TKN value for feed from barn 4 and barn 5 were 2.4% ± 0.2 and 2.3% ± 0.2, respectively. The TKN value for eggs from barn 4 and barn 5 were 1.9% ± 0.2 and 2.0% ± 0.1, respectively.

Table 21. TKN values (% N) of waste samples from the manure barn, Building 4 and Building 5 (uncertainties represent one standard deviation)

Month	Manure Barn	Building 4	Building 5
May-08	2.1 ± 0.3	2.0 ± 0.2	2.0 ± 0.2
Jun-08	2.8 ± 0.2	1.7 ± 0.1	1.7 ± 0.2
Jul-08	1.9 ± 0.3	2.0 ± 0.2	2.0 ± 0.3
Aug-08	1.6 ± 0.2	2.0 ± 0.2	2.0 ± 0.3
Sep-08	2.2 ± 0.1	1.7 ± 0.3	1.9 ± 0.2
Oct-08	1.7 ± 0.1	1.5 ± 0.2	1.4 ± 0.2
Nov-08	1.8 ± 0.2	2.3 ± 0.2	2.2 ± 0.3
Dec-08	1.7 ± 0.2	2.5 ± 0.3	2.0 ± 0.2
Jan-09	1.5 ± 0.1	1.9 ± 0.1	1.6 ± 0.2
Feb-09	1.9 ± 0.2	2.0 ± 0.3	2.0 ± 0.3
Mar-09	2.2 ± 0.2	1.9 ± 0.2	1.6 ± 0.2
Apr-09	2.1 ± 0.3	1.7 ± 0.2	2.1 ± 0.1
May-09	2.1 ± 0.2	1.9 ± 0.2	2.2 ± 0.2
Jun-09	2.1 ± 0.2	1.8 ± 0.2	1.6 ± 0.2
Jul-09	2.1 ± 0.3	1.9 ± 0.2	2.7 ± 0.2
Aug-09	1.9 ± 0.1	1.9 ± 0.1	2.1 ± 0.1
Sep-09	2.2 ± 0.2	1.8 ± 0.2	1.9 ± 0.2
Oct-09	1.9 ± 0.3	1.6 ± 0.2	1.7 ± 0.1
Nov-09	1.8 ± 0.1	2.2 ± 0.3	2.3 ± 0.2
Minimum	1.5 ± 0.1	1.5 ± 0.2	1.4 ± 0.2
Maximum	2.8 ± 0.2	2.5 ± 0.3	2.7 ± 0.2
Mean	2.0 ± 0.3	1.6 ± 0.3	1.9 ± 0.3

Table 22. TKN values (%N) of feed and egg samples of Building 4 and Building 5

Month	Egg 4	Egg 5	Feed 4	Feed 5
May-08	2.0 ± 0.1	1.9 ± 0.2	2.5 ± 0.3	2.2 ± 0.2
Jun-08	2.1 ± 0.2	2.0 ± 0.3	2.6 ± 0.3	1.6 ± 0.2
Jul-08	1.9 ± 0.2	1.7 ± 0.2	2.8 ± 0.2	2.2 ± 0.3
Aug-08	2.0 ± 0.1	2.0 ± 0.2	2.7 ± 0.2	2.4 ± 0.2
Sep-08	2.1 ± 0.2	1.9 ± 0.2	2.6 ± 0.1	2.5 ± 0.2
Oct-08	1.9 ± 0.2	2.0 ± 0.2	2.5 ± 0.2	2.4 ± 0.3
Nov-08	2.2 ± 0.3	2.1 ± 0.3	2.4 ± 0.3	2.3 ± 0.2
Dec-08	2.0 ± 0.3	2.0 ± 0.2	2.5 ± 0.2	2.3 ± 0.1
Jan-09	2.0 ± 0.2	2.0 ± 0.2	2.3 ± 0.2	2.3 ± 0.2
Feb-09	2.1 ± 0.3	2.0 ± 0.3	2.4 ± 0.2	2.2 ± 0.1
Mar-09	1.9 ± 0.2	2.0 ± 0.1	2.3 ± 0.3	2.1 ± 0.2
Apr-09	1.9 ± 0.3	1.9 ± 0.2	2.2 ± 0.1	2.1 ± 0.3
May-09	1.9 ± 0.3	1.8 ± 0.3	2.0 ± 0.2	2.0 ± 0.2
Jun-09	1.5 ± 0.3	1.8 ± 0.2	2.1 ± 0.2	2.6 ± 0.3
Jul-09	1.6 ± 0.1	1.9 ± 0.2	1.9 ± 0.2	2.4 ± 0.1
Aug-09	1.7 ± 0.2	2.2 ± 0.3	2.2 ± 0.3	2.5 ± 0.2
Sep-09	2.0 ± 0.3	2.0 ± 0.2	2.5 ± 0.3	2.2 ± 0.2
Oct-09	1.5 ± 0.2	1.9 ± 0.2	2.5 ± 0.2	2.3 ± 0.2
Nov-09	2.1 ± 0.3	2.1 ± 0.3	2.2 ± 0.2	2.2 ± 0.2
Minimum	1.5 ± 0.3	1.7 ± 0.2	2.0 ± 0.2	1.6 ± 0.2
Maximum	2.2 ± 0.3	2.2 ± 0.3	2.8 ± 0.2	2.6 ± 0.3
Mean	1.9 ± 0.2	2.0 ± 0.1	2.4 ± 0.2	2.3 ± 0.2

Manure management in laying hen facilities can greatly influence NH_3 emission. In comparison, the TKN value of Building 4 was less than that of Building 5 (21%) because Building 4 had a conveyor belt system to separate the manure from the housing facility biweekly, while in Building 5, manure was stored in a pit below. The monthly average values of TKN for manure samples are shown in Figure 68. These results further confirmed that the manure-belt system had a major advantage over the high-rise system in terms of NH_3-N conservation or prevention of NH_3-N emission.

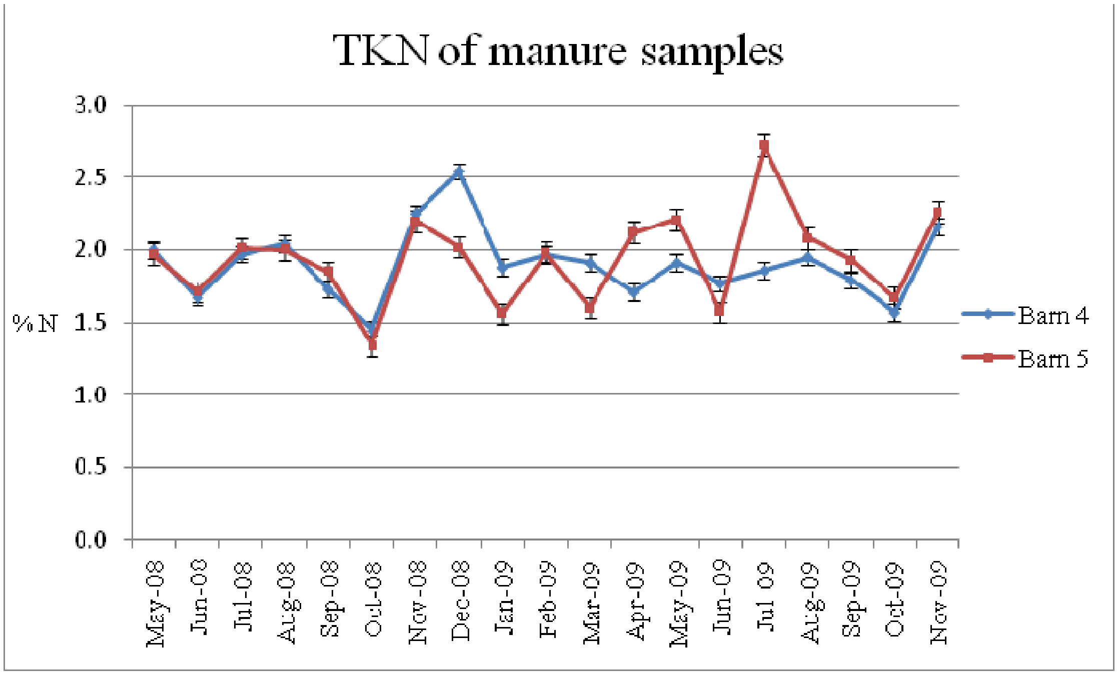

Figure 68. TKN (in %N) of manure samples (error bars represent ± one standard deviation of the four samples collected each month).

The NH_3 values of manure barn, Building 4 and Building 5 were shown in Table 23. The calculated NH_3 values for manure barn, Building 4 and Building 5 were reported in units of mg NH_3 g_{manure}^{-1} as 1.1 ± 0.2, 0.6 ± 0.1 and 0.8 ± 0.1, respectively. The values for Building 4 and Building 5 were likely highest in the summer months due to the higher ambient temperature and higher pH values.

Table 23. Ammonia (NH_3) content of manure samples (mg NH_3 g_{manure}^{-1})

Month	Manure Barn	Building 4	Building 5
May-08	1.6 ± 0.2	0.4 ± 0.1	0.9 ± 0.2
Jun-08	1.4 ± 0.1	0.4 ± 0.1	0.8 ± 0.1
Jul-08	1.4 ± 0.2	0.8 ± 0.1	0.6 ± 0.1
Aug-08	1.1 ± 0.1	0.8 ± 0.1	0.7 ± 0.1
Sep-08	1.3 ± 0.1	0.8 ± 0.1	0.7 ± 0.1
Oct-08	0.6 ± 0.1	0.4 ± 0.1	0.6 ± 0.1
Nov-08	0.9 ± 0.1	0.6 ± 0.1	0.8 ± 0.1
Dec-08	0.8 ± 0.1	0.5 ± 0.1	0.5 ± 0.1
Jan-09	0.5 ± 0.1	0.6 ± 0.1	0.7 ± 0.1
Feb-09	1.1 ± 0.1	0.7 ± 0.2	0.4 ± 0.1
Mar-09	1.4 ± 0.1	0.7 ± 0.1	0.6 ± 0.1
Apr-09	1.5 ± 0.2	0.6 ± 0.2	0.9 ± 0.2
May-09	1.1 ± 0.1	0.6 ± 0.1	1.0 ± 0.1
Jun-09	0.8 ± 0.1	0.5 ± 0.1	0.8 ± 0.1
Jul-09	1.1 ± 0.1	0.6 ± 0.1	0.7 ± 0.1
Aug-09	1.2 ± 0.1	0.8 ± 0.1	0.8 ± 0.1
Sep-09	1.1 ± 0.1	0.8 ± 0.2	0.7 ± 0.1
Oct-09	0.8 ± 0.1	0.5 ± 0.1	0.7 ± 0.1
Nov-09	1.0 ± 0.1	0.6 ± 0.1	0.8 ± 0.1
Minimum	0.5 ± 0.1	0.4 ± 0.1	0.4 ± 0.1
Maximum	1.6 ± 0.2	0.8 ± 0.1	1.0 ± 0.1
Mean	1.1± 0.2	0.6 ± 0.1	0.8 ± 0.1

The pH values are shown in Table 24. As can be seen, the pH of manures handled as solids were in the basic range of 7.5 to 8.5, which results in fairly rapid ammonia volatilization (Susan and Katharine, 2005). Higher temperature in the summer months also favors the volatility of NH_3 to ammonia gas, which was less soluble in water than ammonium (NH_4^+). In addition, emissions decreased immediately after belt cleaning. For example in Building 4 , the results showed that the NH_3 emissions dropped dramatically from 0.78 mg NH_3 g_{manure}^{-1} to 0.43 mg NH_3 g_{manure}^{-1}, a reduction of 45%, when the building was cleaned out in October. In building 5, the emissions dropped from 0.71 mg NH_3 g_{manure}^{-1} to 0.60 mg NH_3 g_{manure}^{-1}, a reduction of 16%, due to barn cleaning operations.

Table 24. pH values of manure barn, Building 4 and Building 5

Month	Manure Barn	Building 4	Building 5
May-08	8.31 ± 0.02	8.17 ± 0.01	8.25 ± 0.01
Jun-08	8.85 ± 0.02	8.08 ± 0.01	8.45 ± 0.01
Jul-08	8.37 ± 0.01	7.64 ± 0.01	7.32 ± 0.01
Aug-08	8.38 ± 0.01	8.39 ± 0.01	8.44 ± 0.01
Sep-08	8.59 ± 0.01	8.25 ± 0.01	8.16 ± 0.01
Oct-08	8.18 ± 0.01	8.32 ± 0.01	8.22 ± 0.01
Nov-08	8.66 ± 0.01	8.15 ± 0.01	8.43 ± 0.01
Dec-08	8.04 ± 0.01	7.83 ± 0.01	7.74 ± 0.01
Jan-09	8.45 ± 0.02	7.60 ± 0.01	8.32 ± 0.01
Feb-09	8.27 ± 0.01	7.80 ± 0.01	8.39 ± 0.01
Mar-09	8.51 ± 0.02	8.01 ± 0.02	8.28 ± 0.01
Apr-09	8.57 ± 0.02	7.89 ± 0.01	8.27 ± 0.01
May-09	8.41 ± 0.01	7.76 ± 0.01	8.26 ± 0.01
Jun-09	8.40 ± 0.01	8.02 ± 0.01	8.20 ± 0.01
Jul-09	8.30 ± 0.01	7.82 ± 0.01	7.90 ± 0.01
Aug-09	8.21 ± 0.01	8.23 ± 0.01	8.22 ± 0.01
Sep-09	8.35 ± 0.01	8.13 ± 0.01	8.02 ± 0.01
Oct-09	8.08 ± 0.02	8.32 ± 0.01	8.05 ± 0.01
Nov-09	8.46 ± 0.03	8.34 ± 0.01	8.25 ± 0.01
Minimum	8.04 ± 0.01	7.60 ± 0.01	7.32 ± 0.01
Maximum	8.85 ± 0.02	8.39 ± 0.01	8.45 ± 0.01
Mean	8.39 ± 0.20	8.04 ± 0.25	8.17 ± 0.27

The barns were scheduled to be emptied out twice a year, in May and October. These findings indicate that a frequent scraping of the manure-belt could reduce NH_3 emissions in the ventilated belt house. Figure 69 shows the monthly average values of NH_3 content for Building 4 and Building 5.

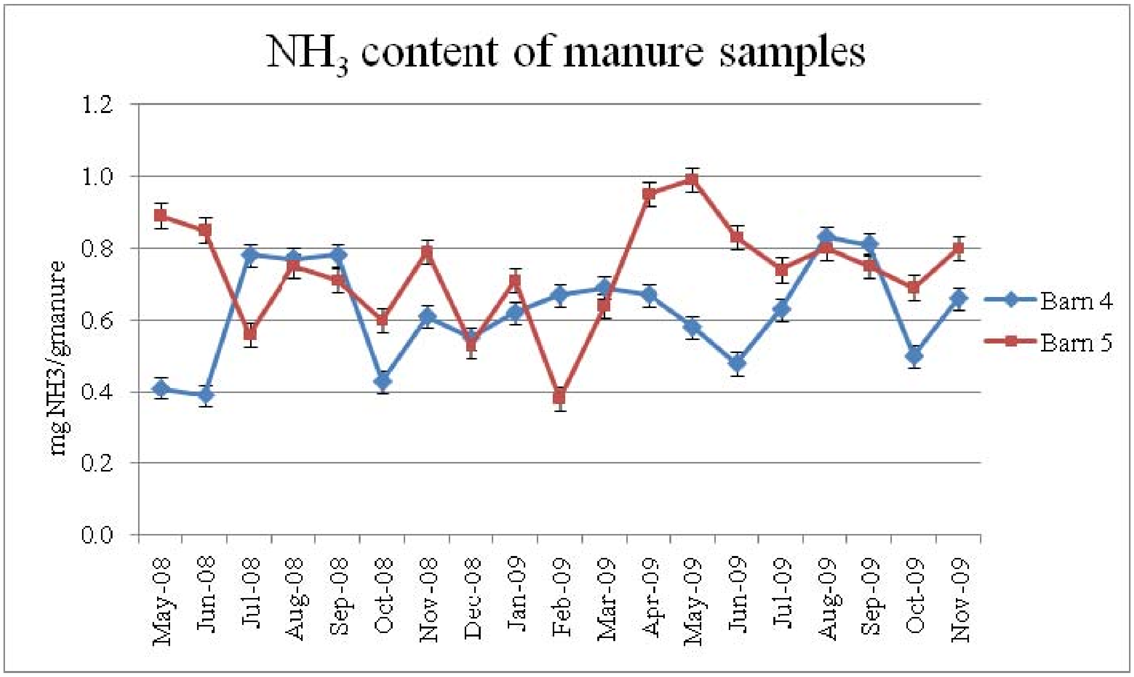

Figure 69. Ammonia content of manure samples (error bars represent ± one standard deviation of the four samples collected each month).

<u>Ammonia Emissions</u>

Ammonia emission rates varied seasonally and diurnally. Ammonia emission rates were found to be higher during the late spring and summer than during the rest of the year. Further analysis of the data indicated that emission rates were higher during the warm weather due to higher ventilation rates and were consistent with earlier studies (Liang et al., 2003).

According to real-time measurements described in previous sections, the ventilation rate results from Building 4 ranged from 2.11 m^3 hr^{-1} $bird^{-1}$ to 3.02 m^3 hr^{-1} $bird^{-1}$, with an average of 2.74 m^3 hr^{-1} $bird^{-1}$. Building 5 ventilation rates ranged from 1.40 m^3 hr^{-1} $bird^{-1}$ to 2.34 m^3 hr^{-1} $bird^{-1}$, with an average of 2.09 m^3 hr^{-1} $bird^{-1}$. It was observed from the collected data that the inside building NH_3 concentrations were higher during the early hours of the morning when most of the fans were not running. However, as the day approached noon (higher temperature) and for most of the afternoon, the inside building concentrations were reduced due to a higher number of fans running, thus leading to higher NH_3 emission (see Ogunlaja, 2009 for further details).

The calculated nitrogen emission factors of Building 4 (manure-belt) and Building 5 (high-rise) are shown in Tables 25 and 26, respectively. A plot of monthly ammonia emissions from Building 4 and Building 5 is shown in Figure 70.

Table 25. Nitrogen emissions (mg NH_3 $bird^{-1}$ day^{-1}) of Building 4 (NF = Nitrogen flux, EM = emission)

Month	NF feed	NF egg	NF manure	EM NH_3	% N loss
May-08	2200 ± 230	870 ± 110	1100 ± 110	260 ± 22	10
Jun-08	1100 ± 310	110 ± 19	790 ± 78	210 ± 29	16
Jul-08	1900 ± 230	570 ± 76	1100 ± 110	300 ± 37	13
Aug-08	2600 ± 230	880 ± 110	1400 ± 130	460 ± 31	14
Sep-08	2700 ± 250	1100 ± 98	1200 ± 140	560 ± 27	17
Oct-08	2500 ± 230	980 ± 83	890 ± 110	790 ± 32	26
Nov-08	2400 ± 190	1100 ± 78	1100 ± 99	510 ± 26	14
Dec-08	2600 ± 210	890 ± 39	1100 ± 110	690 ± 54	26
Jan-09	2400 ± 240	880 ± 61	940 ± 89	690 ± 39	23
Feb-09	2300 ± 170	760 ± 53	1100 ± 110	620 ± 62	22
Mar-09	2500 ± 210	1100 ± 110	940 ± 97	610 ± 59	20
Apr-09	2200 ± 240	740 ± 29	1200 ± 120	290 ± 35	11
May-09	2300 ± 310	620 ± 31	1400 ± 150	380 ± 58	13
Jun-09	1700 ± 270	46 ± 11	1400 ± 150	380 ± 29	18
Jul-09	1600 ± 230	310 ± 21	1200 ± 130	170 ± 37	9
Aug-09	2200 ± 180	7550 ± 120	1200 ± 110	290 ± 31	11
Sep-09	2500 ± 340	1100 ± 120	1100 ± 86	310 ± 42	12
Oct-09	2600 ± 310	1100 ± 130	1100 ± 70	540 ± 87	20
Nov-09	2500 ± 220	1300 ± 110	980 ± 84	320 ± 45	12
Minimum	1100 ± 310	46 ± 11	790 ± 78	170 ± 37	9
Maximum	2700 ± 250	1300 ± 110	1400 ± 130	790 ± 32	26
Mean	2200 ± 420	790 ± 330	1100 ± 160	440 ± 180	16 ± 5

Table 26. Nitrogen emissions (mg NH_3 bird^{-1} day^{-1}) of Building 5 (NF = Nitrogen flux, EM = emission)

Month	NF feed	NF egg	NF manure	EM NH_3	% N loss
May-08	ND	ND	ND	ND	ND
Jun-08	1700 ± 150	310 ± 66	1100 ± 120	320 ± 39	16
Jul-08	1300 ± 210	120 ± 26	790 ± 110	440 ± 32	28
Aug-08	2300 ± 170	910 ± 89	990 ± 99	520 ± 28	18
Sep-08	2700 ± 150	1100 ± 110	1100 ± 110	670 ± 110	20
Oct-08	2600 ± 220	1100 ± 150	910 ± 120	780 ± 230	24
Nov-08	2700 ± 310	1200 ± 71	930 ± 87	770 ± 120	23
Dec-08	2600 ± 160	1100 ± 27	1300 ± 93	440 ± 96	9
Jan-09	2500 ± 130	1100 ± 67	790 ± 82	840 ± 210	27
Feb-09	2400 ± 190	1100 ± 79	750 ± 130	710 ± 99	24
Mar-09	2300 ± 250	770 ± 39	760 ± 98	910 ± 110	32
Apr-09	2200 ± 240	1100 ± 99	740 ± 94	590 ± 95	21
May-09	1800 ± 230	640 ± 120	930 ± 180	260 ± 26	11
Jun-09	1900 ± 130	340 ± 93	1200 ± 230	490 ± 89	20
Jul-09	2200 ± 210	810 ± 150	1100 ± 290	290 ± 39	11
Aug-09	2300 ± 330	880 ± 230	1100 ± 110	470 ± 99	16
Sep-09	2400 ± 360	1100 ± 180	990 ± 48	350 ± 58	14
Oct-09	2600 ± 290	1200 ± 210	990 ± 43	430 ± 94	16
Nov-09	2700 ± 230	1300 ±310	990 ± 28	420 ± 91	15
Minimum	1300 ± 210	120 ± 26	740 ± 94	260 ± 26	9
Maximum	2700 ± 230	1300 ±310	1300 ± 93	910 ± 110	32
Mean	2300 ± 410	890 ± 340	970 ± 160	540 ± 190	20 ± 6

ND: not determined.

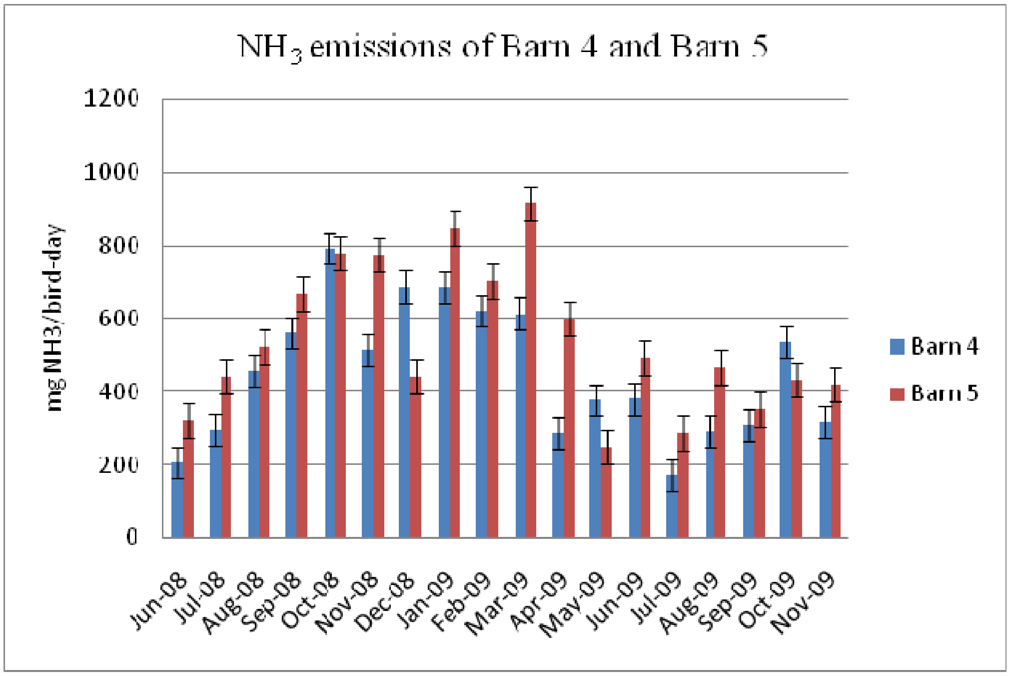

Figure 70. Ammonia emissions (mg NH_3 $bird^{-1}$ day^{-1}) of Building 4 and Building 5 (error bars represent ± one standard deviation of the four samples collected each month).

The average NH_3 emission was 440 ± 180 mg NH_3 $bird^{-1}$ day^{-1} for Building 4 (manure-belt) and 540 ± 190 mg NH_3 $bird^{-1}$ day^{-1} for Building 5 (high-rise). In general, the NH_3 emission from Building 4 was less than from Building 5. The difference in the yearly average values between the two barns was 123 mg NH_3 $bird^{-1}$ day^{-1}, which was equivalent to a 13% reduction in the NH_3 emission. The highest NH_3 emission from Building 4 occurred during the month of October 2008 at a value of 790 mg NH_3 $bird^{-1}$ day^{-1}, while the high value in Building 5 was 914 mg NH_3 $bird^{-1}$ day^{-1} during the month of March 2009. In addition, during the warm months from June to August, the emissions from both Building 4 and Building 5 were lower than the values in the cold months. Observations showed that the higher values of the TKN and NH_3 during the warm months caused lower values of nitrogen emission.

The percentage of nitrogen loss to the atmosphere, presumably gas-phase NH_3, was calculated as the ratio of the nitrogen emissions to the total input nitrogen (in this study, total nitrogen input was NF feed) and multiplied by 100%. The percentage of nitrogen loss per bird to the atmosphere averaged 16% for Building 4 and 20% for Building 5

In a review of ammonia emission factors (Faulkner et al., 2008), some recommended factors were provided for the U.S agriculture system. For dry manure handling systems, an emission factor of 0.19 kg NH_3 $bird^{-1}$ $year^{-1}$ or 520 mg NH_3 $bird^{-1}$ day^{-1} was given. For wet manure handling systems, 0.11 kg NH_3 $bird^{-1}$ $year^{-1}$ or 300 mg NH_3 $bird^{-1}$ day^{-1} was given. These values were similar to the results obtained in the current study via the nitrogen balance approach. The average value obtained in this study for Building 4 was 440 ± 180 mg NH_3 $bird^{-1}$ day^{-1} and the average for Building 5 was 540 ± 190 mg NH_3 $bird^{-1}$ day^{-1}. Other investigators have also found that barns that employ the belt system to remove the manure and separate it from the housing tended to have lower emission factors (Fabbri et al., 2007). In the results obtained in this study, the same reduced emissions were observed. The average emission factor for Building 4 (manure-belt) was 99 mg NH_3 bird^{-1} day^{-1}, (18%) less than the emission factor for Building 5 (high-rise).

In European studies, the emission factors for barns that employed a manure-belt system were generally around 95-170 mg NH_3 bird^{-1} day^{-1}, and barns that contained manure pits were around 380-420 mg NH_3 bird^{-1} day^{-1}. The average factor obtained for the belt system in this research was 440 ± 180 mg NH_3 bird^{-1} day^{-1}, which was about 270 mg NH_3 bird^{-1} day^{-1} higher than the European studies. The average factor obtained for the manure pits in this research was 540 ± 190 mg NH_3 bird^{-1} day^{-1}, which was about 120 mg NH_3 bird^{-1} day^{-1} higher than the values in European studies. 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. In this study, the manure-belt management system showed an averaged decrease NH_3 emission rate of approximately 21% compared to the observed high-rise management system.

According to Table 24, the average pH value for the manure barn was 8.39 ± 0.20, which was higher than the pH of Building 4 and Building 5, which were 8.04 ± 0.25 and 8.17 ± 0.27, respectively. This would suggest that the manure samples in the manure barn have a higher level of ammonia content (vs. ammonium, NH_4^+) compared to Building 4 and Building 5. Using the TKN method, the yearly average ammonia content of manure sample from May 2008 to November 2009 was calculated as 1.1 ± 0.2 mg NH_3 g_{manure}^{-1}, which was higher than that of Building 4 (0.62 ± 0.1 mg NH_3 g_{manure}^{-1}) and Building 5 (0.73 ± 0.1 mg NH_3 g_{manure}^{-1}).

The ammonia in the ambient air of the manure barn was measured several times during this study: during October 2008 (14th and 21st), December 2008 (2nd and 23rd) May 2009 (12th and 19th), and September 2009 (8th and 15th) using impinger and IC methods. The average value for the eight samples was 13.7 ± 3.0 ppm. This value was also higher than the average ammonia concentrations observed in air of Building 4 (11.9 ± 2.9 ppm) and Building 5 (12.7 ± 3.1 ppm). The sample measurements showed that the ammonia in the manure barn air was higher than in Building 4 and Building 5. This may be due to lower ventilation rates in the manure barn. It should be noted, however, that the differences across the averages from all the systems (manure barn, Buildings 4 and 5) are statistically insignificant at one standard deviation.

The solid content of manure, feed and egg samples also played an important factor in the determined NH_3 emission levels. Higher moisture content in the manure results in a higher ratio of NH_3/TKN_{manure} stored in the manure which results in a higher percentage of nitrogen loss. The results indicated that the quicker the manure dried, the less NH_3 was emitted. Table 27 shows the total solid and volatile solid content of manure samples.

Tables 28 and 29 show the total solid and volatile solid content of feed and egg samples. The results showed that the less volatile solid the sample contained, the lower the TKN and NH_3 values. The yearly average volatile solid content of manure samples (in %) for Building 4 and Building 5 were 21.9 ± 1.3% and 22.5 ± 1.8%, respectively. The yearly average volatile solid content of egg samples for Building 4 and Building 5 were 20.1 ± 1.4% and 21.6 ± 1.9%, respectively. The yearly average volatile solid content of feed samples for Building 4 and Building 5 were 64.7 ± 3.5% and 63.9 ±3.2%, respectively.

Table 27. Total solid and volatile solid of manure samples

Month	Barn 4		Barn 5	
	%TS	**%VS**	**%TS**	**%VS**
May-08	35.4 ± 1.7	20.4 ± 1.4	33.6 ± 2.1	19.2 ± 1.1
Jun-08	40.9 ± 2.1	20.0 ± 0.8	36.3 ± 1.6	20.6 ± 0.7
Jul-08	40.1 ± 1.6	23.0 ± 1.2	35.1 ± 1.1	22.4 ± 0.8
Aug-08	38.8 ± 1.6	25.0 ± 1.5	42.0 ± 1.7	25.5 ± 1.2
Sep-08	34.0 ± 1.4	22.6 ± 1.1	40.8 ± 1.8	26.2 ± 1.6
Oct-08	37.0 ± 1.6	21.2 ± 1.6	36.0 ± 1.9	23.5 ± 0.9
Nov-08	41.6 ± 1.8	22.4 ± 1.1	36.6 ± 2.1	22.2 ± 1.4
Dec-08	35.7 ± 1.9	23.1 ± 1.7	35.2 ± 2.3	23.2 ± 1.6
Jan-09	41.6 ± 2.2	24.4 ± 2.0	36.4 ± 2.1	22.7 ± 2.1
Feb-09	39.5 ± 1.4	21.4 ± 1.8	38.3 ± 1.5	22.4 ± 1.3
Mar-09	37.7 ± 1.1	21.5 ± 0.7	35.7 ± 2.1	21.9 ± 2.3
Apr-09	36.0 ± 1.5	21.2 ± 1.4	32.8 ± 1.7	20.4 ± 1.2
May-09	35.1 ± 1.8	20.7 ± 1.2	34.2 ± 1.1	20.5 ± 1.6
Jun-09	39.2 ± 1.7	21.0 ± 1.1	34.7 ± 1.4	19.5 ± 1.7
Jul-09	41.0 ± 2.0	21.3 ± 1.6	34.7 ± 1.0	22.6 ± 1.5
Aug-09	39.0 ± 2.4	21.3 ± 1.4	40.2 ± 1.6	23.1 ± 1.9
Sep-09	35.0 ± 1.4	23.0 ± 1.8	38.6 ± 1.8	22.8 ± 1.5
Oct-09	37.0 ± 1.9	21.7 ± 1.2	36.8 ± 2.0	23.6 ± 1.3
Nov-09	40.5 ± 2.5	21.2 ± 1.3	37.6 ± 1.9	23.4 ± 1.2
Minimum	34.0 ± 1.4	20.0 ± 0.8	32.8 ± 1.7	19.2 ± 1.1
Maximum	41.6 ± 2.2	25.0 ± 1.5	42.0 ± 1.7	26.2 ± 1.6
Mean	38.2 ± 2.5	21.9 ± 1.3	36.6 ± 2.3	22.5 ± 1.8

TS: total solid, VS: volatile solid.

Table 28. Total solid and volatile solid of feed samples (%)

Month	Feed 4		Feed 5	
	%TS[a]	%VS[b]	%TS[a]	%VS[b]
May-08	87.5 ± 1.8	57.7 ± 1.3	87.2 ± 2.1	51.2 ± 1.5
Jun-08	88.3 ± 2.3	55.1 ± 1.5	88.6 ± 1.3	53.2 ± 2.0
Jul-08	86.9 ± 2.5	62.7 ± 1.7	86.9 ± 1.6	58.9 ± 1.5
Aug-08	88.8 ± 1.6	73.4 ± 1.4	87.8 ± 1.4	68.7 ± 1.7
Sep-08	88.0 ± 1.7	71.9 ± 1.8	88.2 ± 1.7	70.2 ± 1.3
Oct-08	87.7 ± 1.0	66.7 ± 2.1	82.8 ± 1.5	65.9 ± 1.8
Nov-08	88.7 ± 1.4	63.4 ± 2.7	84.5 ± 1.4	63.7 ± 2.1
Dec-08	88.8 ± 1.6	63.5 ± 1.8	86.4 ± 1.8	65.9 ± 1.0
Jan-09	86.8 ± 1.9	63.0 ± 1.9	86.6 ± 1.1	66.0 ± 1.5
Feb-09	87.2 ± 2.1	63.0 ± 2.3	84.7 ± 1.6	58.7 ± 1.6
Mar-09	85.2 ± 1.4	62.4 ± 2.4	86.1 ± 1.4	67.4 ± 1.4
Apr-09	86.4 ± 1.5	65.2 ± 1.5	87.7 ± 1.0	65.3 ± 1.3
May-09	87.3 ± 1.6	62.3 ± 1.3	88.5 ± 1.6	61.4 ± 1.7
Jun-09	87.3 ± 1.7	61.9 ± 2.1	89.4 ± 1.8	69.1 ± 2.1
Jul-09	89.9 ± 1.3	63.6 ± 1.5	85.2 ± 2.0	62.3 ± 1.1
Aug-09	85.7 ± 2.3	70.1 ± 1.8	85.3 ± 1.2	66.3 ± 1.8
Sep-09	89.0 ± 2.1	69.6 ± 1.4	87.5 ± 1.5	68.3 ± 1.2
Oct-09	88.8 ± 1.6	67.4 ± 1.4	84.3 ± 1.3	66.7 ± 1.4
Nov-09	87.2 ±1.8	65.5 ± 1.3	85.3 ± 1.7	65.4 ± 1.2
Minimum	85.2 ± 1.4	55.1 ± 1.5	82.8 ± 1.5	51.2 ± 1.5
Maximum	89.9 ± 1.3	73.4 ± 1.4	89.4 ± 1.8	70.2 ± 1.3
Mean	87.7 ± 1.2	64.7 ± 3.5	86.5 ± 1.8	63.9 ± 3.2

[a]TS: total solid, [b]VS: volatile solid.

Table 29. Total solid and volatile solid of egg samples (%)

Month	Egg 4		Egg 5	
	%TS[a]	%VS[b]	%TS[a]	%VS[b]
May-08	20.3 ± 1.3	17.3 ± 1.0	19.6 ± 1.2	16.8 ± 1.3
Jun-08	20.5 ± 0.9	18.2 ± 1.3	24.3 ± 1.3	22.1 ± 1.5
Jul-08	20.2 ± 1.2	17.5 ± 1.5	20.6 ± 1.5	19.66 ± 0.7
Aug-08	22.1 ± 1.5	20.1 ± 1.9	22.5 ± 1.1	21.5 ± 1.1
Sep-08	22.8 ± 1.9	20.7 ± 1.4	23.2 ± 1.4	22.0 ± 1.0
Oct-08	22.2 ± 1.3	20.7 ± 1.6	24.0 ± 1.8	21.2 ± 1.4
Nov-08	20.0 ± 1.5	19.1 ± 1.8	26.3 ± 1.0	24.8 ± 1.1
Dec-08	21.3 ± 1.7	20.2 ± 1.5	23.3 ± 0.8	21.0 ± 1.0
Jan-09	24.1 ± 1.8	22.7 ± 1.4	25.2 ± 1.2	24.1 ± 1.0
Feb-09	23.1 ± 1.3	21.2 ± 1.7	25.0 ± 1.4	23.2 ± 1.3
Mar-09	22.9 ± 1.5	21.2 ± 1.5	26.6 ± 1.5	24.5 ± 1.1
Apr-09	21.0 ± 1.2	19.9 ± 1.3	24.2 ± 1.2	22.5 ± 1.8
May-09	21.1 ± 1.1	18.7 ± 1.4	21.9 ± 1.6	18.8 ± 1.5
Jun-09	21.8 ± 1.7	19.5 ± 1.3	23.1 ± 1.4	22.0 ± 1.4
Jul-09	22.0 ± 2.1	20.8 ± 1.7	21.2 ± 1.2	20.1 ± 1.6
Aug-09	23.1 ± 1.3	21.4 ± 1.5	23.9 ± 1.4	22.0 ± 1.7
Sep-09	21.9 ± 2.0	21.0 ± 1.2	22.7 ± 1.3	19.8 ± 1.9
Oct-09	23.2 ± 1.4	21.3 ± 1.1	23.7 ± 1.5	21.5 ± 1.3
Nov-09	21.2 ± 1.7	19.6 ± 1.5	24.8 ± 1.6	22.1 ± 1.3
Minimum	20.0 ± 1.5	17.3 ± 1.0	19.6 ± 1.2	16.8 ± 1.3
Maximum	24.1 ± 1.8	22.7 ± 1.4	26.6 ± 1.5	24.1 ± 1.0
Mean	21.9 ± 1.2	20.1 ± 1.4	23.5 ± 1.8	21.6 ± 1.9

[a]TS: total solid, [b]VS: volatile solid

CONCLUSIONS

Real-time Gaseous & Particulate Emissions

Ammonia (NH_3), ethanol (EtOH), nitrous oxide (N_2O), carbon dioxide (CO_2) and particulate matter ($PM_{2.5}$ and PM_{10}) emissions were monitored in northern Utah at two poultry (layer) buildings employing differing manure management schemes. The first unit had in-house prolonged manure storage (Building 5, high-rise), the ground floor was for manure storage and the hens were housed on the first floor with an average bird count of 51,614. The second unit had a manure removal system for lower environmental impact, wherein the wastes were deposited and partially dried on ventilated manure-belts (Building 4, manure-belt). This unit had an average bird count of 116,040. The data were collected continuously from early early September 2008 to early October 2009 (the sampling data was interrupted due to the breakdown of the INNOVA 1412) using a photoacoustic field gas monitor INNOVA 1412 and a system of pumps that sequentially, selectively, and continuously measured NH_3, EtOH, CO_2 and N_2O and an optical particle counter (OPC) to continuously measure PM over a sampling period of September 2008 to January 2009. The ventilation rates were also continuously recorded from mid-September 2008 to January 2009 so that the pollutant concentration could be converted to pollutants emission factors.

As expected, there was a direct correlation between the inside building temperature and the building ventilation rates. The results obtained during this study verify that a high inside building temperature leads to a high ventilation rate and a high in-house pollutant concentration leads to a high emission rate of pollutants. Over the six month sampling period, the observed average temperatures for the west and east fan banks of the high-rise building were 41.3±20 and 39.5±23°C, respectively, and the average inside relative humidities during the same period were 43.5±7.5 and 48.2±8.4%, respectively. Furthermore, the observed average temperatures for the west and east fan banks of the manure-belt building were 40.2±19 and 36.8±20°C, respectively, and the average inside relative humidities during the same period were 44.1 ±7.9 and 49±8.1%, respectively. Therefore, the inside temperature for both buildings was approximately the same.

Ultimately, the normalized ventilation rates for each building were very similar. The ventilation rates ranged from 0.80 $m^3\ hr^{-1}\ bird^{-1}$ to 4.80 $m^3\ hr^{-1}\ bird^{-1}$, with an average of 2.02 $m^3\ hr^{-1}\ bird^{-1}$ for the high-rise barn and from 0.80 $m^3\ hr^{-1}\ bird^{-1}$ to 6.0 $m^3\ hr^{-1}\ bird^{-1}$, with an average of 2.20 $m^3\ hr^{-1}\ bird^{-1}$ for the manure-belt building over the sampling period of September, October, November, and December 2008 and January 2009. The data before September 2008 were lost due to computer failure.

The average NH_3 emission factors were 72±17 g $day^{-1}\ AU^{-1}$ for the high-rise system and 9.1±7 g $day^{-1}\ AU^{-1}$ for the manure-belt. The manure-belt emission rates reported herein were somewhat lower than that given for the corresponding technique reported by Liang et al., 2005 (17.5 g $day^{-1}\ AU^{-1}$) and were significantly lower than those reported by Arogo et al., 2006 (303 g $day^{-1}\ AU^{-1}$) for the same management technique. Similarly, the emission rate for the high-rise house was lower than that reported by Liang et al., 2005 (298 g $day^{-1}\ AU^{-1}$) and also lower than that of Arogo et al., 2006 (482 g $day^{-1}\ AU^{-1}$) for the same technique. Holistically, these results confirm that there is a reduction in ammonia emission when a manure-belt management technique is used as compared to a high-rise management technique. The NH_3 emission reduction factor for the manure-belt technique compared to the high-rise technique in this study was 87%. This was because of the greater levels of manure in the high-rise building (longer in-house storage) compared to the manure-belt building. In addition, despite the fact that the bird population in the manure-belt building was almost double the bird population in the high-rise building, the ammonia emission factors recorded for the high-rise building was higher than that of the manure-belt. This signifies the effectiveness of the manure-belt technique over the high-rise in terms of ammonia management and, by extension, environmental protection. Furthermore, employing the manure-belt technique would likely be very favorable and more profitable to poultry producers since larger numbers of bird can be managed with the same building size as that of the high-rise building but not produce as high of ammonia pollutant, which could affect not only the environment but the birds and the poultry workers, as well.

The daily variability of ammonia emission factors from each individual house was relatively small compared to emission variability between the two houses with different management techniques. It was observed that the daily variability in emission factors from an individual house was related to both the variation in ammonia levels and fluctuations in ventilation rate over the sampling period. Also, the ammonia levels outside the house were found to consistently average less than 1 ppm.

No significant average concentrations, and therefore emissions, were observed for nitrous oxide (N_2O), hydrogen sulfide (H_2S), sulfur dioxide (SO_2), or ethanol (EtOH) in either poultry building. The measured concentrations were consistently close to or below the instrumental minimum detection limits. Therefore, due to the insignificance of the results obtained, this study found emissions of N_2O, H_2S, SO_2, and EtOH from the poultry buildings to be negligible, regardless of the management techniques employed.

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 1,540 ppm were observed for the manure-belt building, while the high-rise building concentrations ranged from 835 ppm to 1,621 ppm and showed a mean of 1,256 ppm. The emission rates for the manure-belt building ranged from 61 lb yr^{-1} $bird^{-1}$ to 109 lb yr^{-1} $bird^{-1}$, with a mean of 84 lb yr^{-1} $bird^{-1}$, and the high-rise building rates ranged from 61 lb yr^{-1} $bird^{-1}$ to 94 lb yr^{-1} $bird^{-1}$, with a mean of 84 lb yr^{-1} $bird^{-1}$. Although the bird population in the two houses differed (manure-belt averaged 116,040 birds and high-rise averaged 51,614 birds), this was not reflected in the CO_2 emission factors. This demonstrates that all the CO_2 production, per bird, between the two houses is equivalent and suggests that the data collection and the emissions analyses protocols are reasonable.

The particulate matter (PM) was also measured continuously from September 2008 to January 2009. Throughout the sampling period, the mean $PM_{2.5}$, PM_{10}, and TSP concentrations were 2.62±0.6 μg m^{-3}, 40±5 μg m^{-3}, and 92±13 μg m^{-3} for the high-rise building and 3.40±0.16 μg m^{-3}, 89±10.86 μg m^{-3}, and 195±31.87 μg m^{-3} for the manure-belt building, demonstrating a significant contrast between the two manure management approaches. The contributions of the $PM_{2.5}$ and PM_{10} towards the TSP in both buildings were on the same order (2.9% and 43%, respectively, for the high-rise and 1.7% and 46%, respectively, for the manure-belt). In general, the overall PM in the manure-belt building was higher than that observed in the high-rise building. This was likely due to the higher number of birds in the manure-belt building compared to the high-rise building. Over the 5-month sampling period available, the average manure-belt building $PM_{2.5}$, PM_{10}, and TSP emission rates were 33±17 g min^{-1}, 821±316 g min^{-1}, and 1,691±775 g min^{-1}, respectively, and 28.4±10 g min^{-1}, 382±286 g min^{-1}, and 997±462 g min^{-1} for the high-rise building, respectively. However, when normalized by bird counts, the difference in all PM emissions became insignificant at one standard deviation. These emission rates on a per bird basis for $PM_{2.5}$, PM_{10}, and TSP emissions are 0.41±0.21 g $bird^{-1}$ day^{-1}, 10.2±3.9 g $bird^{-1}$ day^{-1}, and 21.0±9.6 g $bird^{-1}$ day^{-1}, respectively, for the manure-belt barn and 0.79±0.28 g $bird^{-1}$ day^{-1}, 10.7±8.0 g $bird^{-1}$ day^{-1}, and 27.8±1.20 g $bird^{-1}$ day^{-1} for the high-rise barn, respectively.

The summary of all the pollutants monitored during this phase of the study, in a variety of common units, is presented in Table 30.

Table 30. Summary of the average ventilation rates and emission factors for NH_3, N_2O and CO_2 gases and size-specific particulate matter

		Manure-belt Building			High-Rise Building		
		Mean	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**
Ventilation Rate	**m^3 hr^{-1} $bird^{-1}$**	2.2 ± 1.8	0.80	6.00	2.02 ± 1.10	0.80	4.60
	m^3 hr^{-1} AU^{-1}	579 ± 474	211	1579	532 ± 289	211	1211
Ammonia (NH_3)	**kg hr^{-1} $bird^{-1}$**	1.23e-06 ± 9.42e-07	2.94e-06	4.64e-06	1.14e-05 ± 3.62e-06	4.62e-06	1.44e-05
	lbs yr^{-1} $bird^{-1}$	0.02 ± 0.02	0.01	0.09	0.22 ± 0.07	0.09	0.28
	kg hr^{-1} AU^{-1}	3.23e-04 ± 2.48e-04	7.75e-05	1.22e-03	2.99e-03 ± 9.52e-04	1.22e-03	3.79e-03
	g day^{-1} AU^{-1}	7.76 ± 5.95	1.86	29.3	71.8 ± 22.8	29.2	91.0
	g yr^{-1} $bird^{-1}$	10.8 ± 8.25	2,58	40.6	99.6 ± 31.7	40.5	126.3
NH_3 from N mass balance	**mg $bird^{-1}$ d^{-1}**	440 ± 180	-----	-----	540 ± 190	-----	-----
	g day^{-1} AU^{-1}	116 ± 47.4	-----	-----	142 ± 50.0	-----	-----
NH_3 literature values[1]	**g day^{-1} AU^{-1}**	14 – 224			86 -523		
Nitrous Oxide (N_2O)	**kg hr^{-1} $bird^{-1}$**	n.d.	n.d.	n.d.	2.84e-07 ± 2.17e-07	n.d.	7.58e-07
	lbs yr^{-1} $bird^{-1}$	n.d.	n.d.	n.d.	0.010 ±0.004	n.d.	0.010
	g day^{-1} AU^{-1}	n.d.	n.d.	n.d.	3.25 ± 1.30	n.d.	3.25
N_2O literature values[1]	**g day^{-1} AU^{-1}**	0.4 – 26 (also given as 2% of total N emissions)					
Carbon Dioxide (CO_2)	**kg hr^{-1} $bird^{-1}$**	4.16e-03 ± 1.20e-03	3.16e-03	5.65e-03	4.16e-03 ± 1.07e-03	3.14e-03	4.85e-03
	lbs yr^{-1} $bird^{-1}$	80.4 ± 23.3	61.1	109	80.4 ± 20.6	60.7	93.6
	g day^{-1} AU^{-1}	99.9 ± 28.9	75.9	136	99.9 ± 25.6	75.4	116
$PM_{2.5}$	**g min^{-1}**	33.0 ± 17.0	22.1	51.3	28.4 ± 10.0	12.5	70.5
	g $bird^{-1}$ day^{-1}	0.41 ± 0.21			0.79 ± 0.28		
	kg day^{-1} AU^{-1}	0.11 ± 0.0			0.21 ± 0.07		
PM_{10}	**g min^{-1}**	821 ± 316	400	1691	332 ± 286	45.5	1875
	g $bird^{-1}$ day^{-1}	10.2 ± 3.9			10.7±8.0		
	kg day^{-1} AU^{-1}	2.78 ± 1.03			2.80 ± 2.10		
TSP	**g min^{-1}**	1691 ± 775	435	4800	997 ± 462	48.5	7156
	kg day^{-1} AU^{-1}	21.0 ± 9.6			27.8±1.20		
	g $bird^{-1}$ day^{-1}	5.52 ± 2.53			7.32 ± 3.39		
Resp. (≤ 5 µm) lit. values[1]	**kg day^{-1} AU^{-1}**	0.012 (range 0.002 - 0.020)					
Inhal. (≤ 15) lit. values[1]	**kg day^{-1} AU^{-1}**	0.08 (range: 0.02 - 0.20)					

[1]refer to the Background and Previous Emission Studies section of this document

Grab Sample IC and TKN Analysis

By using impinger bubbling as a sampling method, ammonia was successfully detected and quantified using ion chromatography and ion conductivity detection. The yearly average concentration of ammonia in ambient air from July 2008 to November 2009 was calculated at 11.9 ± 2.9 ppm at the manure-belt barn and 12.7 ± 3.1 ppm at the high-rise barn. No organic amines were detected in the collected ambient air samples. This result is possibly due to low concentrations that prevented the amines from having sufficient vapor pressure to be sampled by the impinger method. Thus, the hypothesis of significant concentrations of organic amines being present in ambient air in the various barns is invalid. Comparison of the developed IC method with measurements made using a photo acoustic field gas monitor (INNOVA) in another part of the overall study showed that the two methods measured similar ammonia concentrations in the ambient air. Further studies to determine if any organic amines are tied-up within the manure as non-volatile species (chemisorbed or physisorbed to the manure) will require an alternate analysis method. One approach to answering this question might involve using solvent extraction of the manure samples followed by ion chromatography.

Using the TKN method, chicken manure, feed, and eggs were sampled and analyzed to determine their percent nitrogen. The obtained results revealed that drying and removing the manure by means of a manure-belt system reduced emissions. These values were comparable to values from previous studies in Europe. Using the TKN method, the calculated ammonia emission factors in this study were 440 ± 180 mg NH_3 $bird^{-1}$ day^{-1} for Building 4 (manure-belt) and 540 ± 190 mg NH_3 $bird^{-1}$ day^{-1} for Building 5 (high-rise). Comparing the TKN method with the emission factors studies in Europe, the emission factors from this study are higher than in Europe. This difference is believed to be due to the differences in housing facilities, manure management practices, climate, etc. between the U.S and Europe. Based on this work and other studies, the poultry producers should apply strategies to reduce ammonia emissions. These strategies include application of urease inhibitors (e.g. N-n-butyl thiophosphoric triamide, cyclohexylphosphoric triamide, and phenyl phosphorodiamidate), separation of feces and urine in order to prevent hydrolysis of urea by using the manure-beltsystems, manipulating dietary nitrogen content and availability (this may be accomplished through the addition of acidogenic phosphorus sources and/or calcium salts to feed in order to counteract the pH increases that occur as a result of urea hydrolysis), etc. (National Research Council, 2003; Kurvits and Marta, 1998).

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APPENDICES

Proceedings of Workshop on Agricultural Air Quality: State of the Science, 2006 (CD version)

Ogunlaja's thesis (electronic version)

Dinh's thesis (electronic version)