MONITORING AND MODELING OF DIURNAL AND SEASONAL ODOUR AND GAS EMISSIONS FROM DIFFERENT TYPES OF SWINE ROOMS

A Thesis Submitted to the College of

Graduate Studies and Research

In Partial Fulfillment of the Requirements

For the Degree of Master of Science

In the Department of Agricultural and Bioresource Engineering

University of Saskatchewan

Saskatoon

By

YUANYUAN WANG

PERMISSION TO USE

In presenting this thesis in partial fulfilment of the requirements for a Postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department or the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to the University of Saskatchewan in any scholarly use which may be made of any material in my thesis.

Requests for permission to copy or to make other use of material in this thesis in whole or part should be addressed to:

Head of the Department of Agricultural and Bioresource Engineering

University of Saskatchewan

Saskatoon, Saskatchewan S7N 5A9

ACKNOWLEDGEMENTS

It is hard to condense into few sentences to express my sincere appreciation to my supervisor Dr. Huiqing Guo, for her continued guidance and encouragement throughout the past two years. It is really a precious experience for me to learn and grow up from the opportunity she provided. Further acknowledgements extended to advisory committee member Dr. Venkatesh Meda, Dr. Bernardo Predicala, and external examiner Dr. Yang Shi for their great advice and suggestions.

The author is indebted to Electronics Technician Toni Schleicher, research assistant Dena Brunette and Wenhao Dai for their great contribution to this project. Without their assistance in signal conditioning, system installation and sample transportation, the project could not be so successful and rewarding. Special thanks also go to Dr. Yongxin Li, Dr. Xiaowen Zhang, Zimu Yu, Yanan Xing, Yuguo Li, Randy Lorenz, Louis Roth, Mike Miller, and Darin Richman in the process of data collecting and sample analyzing. I value all the friends I have made in the Department of Agricultural and Bioresource Engineering and in the barn of Prairie Swine Center.

Financial supports from the Natural Sciences and Engineering Research Council of Canada and the Saskatchewan Agricultural Development Fund are immensely acknowledged.

Finally, and most importantly, thank you to my family and friends in China for encouraging me through master program and always.

ABSTRACT

The issue of odour, greenhouse gas emissions and indoor air quality in swine buildings have become a great concern for the neighbouring communities as well as governments. Air dispersion models have been adopted widely as an approach to address these problems which determine science-based distance between livestock production site and neighbours. However, no existing model considers the diurnal and seasonal variations of odour, gas (ammonia, hydrogen sulphide, greenhouse gas), and dust concentrations and emissions, which may cause great uncertainty. The primary objective of this project is to monitor and model the diurnal and seasonal variations of odour, gases, and dust concentrations and emissions from nursery, farrowing, and gestation rooms. Additionally, this study tried to quantify the greenhouse gas contribution from swine buildings and evaluate the indoor air quality of swine barns.

Strip-block experimental design was used to measure the diurnal variation of odour and gas concentrations and emissions in PSC Elstow Research Farm. It was found that: 1) odour and gas concentrations in winter were significantly higher than those in mild and warm weather conditions for all three rooms ($P<0.05$); 2) the nursery room had higher level of odour and gas concentration and emission than the other two types of rooms, no significant difference existed between the farrowing and gestation rooms ($P>0.05$); 3) significant diurnal variations occurred in August and April ($P<0.05$) for odour and some gas concentrations and emissions, while no significant diurnally variations were found in February ($P>0.05$); 4) apparent diurnal variation patterns were observed in August and April for NH_3, H_2S and CO_2 concentrations, being high in the early morning and low in the late afternoon; 5) positive correlation was found between odour concentrations and NH_3, H_2S, and CO_2 concentrations, respectively.

A whole year (August 2006 to July 2007) monitoring of odour, gas and dust concentrations and emissions revealed that: 1) significant seasonal effect on odour and gas concentrations and emissions, total dust concentrations and dust depositions were observed (P<0.05), but no specific variation pattern was discovered for odour and gas emissions; 2) the total greenhouse gas emission from all the rooms in the gestation, nursery and farrowing area was 2956 CO_2 equivalent tons per year, where gestation area, nursery area, and farrowing area accounted for 39.3 %, 37.2% and 23.5%, respectively; the CO_2 emission contributed 53.4% to the total greenhouse emission, and CH4 contributed to 43.9%, 2.7% for N_2O; N_2O could be considered negligible; 3) indoor air quality of the swine barn met the requirements set by the Occupational Health and Safety Regulations (1996) of Saskatchewan for NH_3, H_2S, and CO_2.

Statistical models were developed for each type of room to predict the odour and gas concentrations and emissions based on four variables: ventilation rate, room temperature, ambient temperature, and animal unit. The predicted results showed agreeable with measured values for most models (R^2 = 0.56-0.96). Generally, gas prediction models performed better (R^2=0.61-0.96) than odour prediction models (R^2=0.56-0.85).

This study was conducted in the province of Saskatchewan throughout one year and the results could be used as representative data for Canada Prairies. Due to the large diurnal and seasonal variabilities of odour emissions, it was recommended to take multiple measurements of odour emission rate under different weather conditions in order to improve the accuracy of air dispersion modeling.

TABLES OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOTATION

E	Emission
OU	Odour Unit
V	Ventilation rate
ΔC	Concentration difference
α	Significance level
P	p-value
A	Traverse area
AU	Animal Unit
NH_3	Ammonia
H_2S	Hydrogen sulphide
CO_2	Carbon dioxide
CH_4	Methane
N_2O	Nitrous oxide
OC	Odour concentration
OE	Odour emission
NC	Ammonia concentration
NE	Ammonia emission
HC	Hydrogen sulphide concentration
HE	Hydrogen sulphide emission
CC	Carbon dioxide concentration
CE	Carbon dioxide emission
CHC	Methane concentration
CHE	Methane emission
FB	Fractional bias based on average
$S.D.$	Standard deviation
MSE	Mean square error
R^2	R square, Person's coefficient

1 INTRODUCTION

The pork production in Canada is approximately 31 million hogs marketed in 2006 (Canadian Pork Council, 2007). This intensive industry brings along the emissions of odour, ammonia (NH_3), hydrogen sulphide (H_2S), and greenhouse gas from large size of swine production facilities. The air emissions cause frequent complaints about strong and objectionable odours voiced by neighbours (Jacobson et al., 2002) Moreover, the various substances in air emissions also contribute to environmental degradation (National Academy of Sciences, 2003; Schiffman, 1998). Odour nuisance issue affects the acceptability of livestock farming in the vicinity of residential area (Schiffman 1998; O'Neill 1991). Currently, disputes or even lawsuits between swine producers and neighbouring residents have been a great burden to the individual farmers and the industry.

Over the past decades, many regulations have been promulgated to guide and control facilities, locations, construction, and operation in the U.S. and other countries (Parker, 1999). Meanwhile, some abatement technologies and strategies have been implemented to reduce the odour and gas emissions such as chemical and biological treatment of manure, dietary manipulation, liquid–solid separation, biofiltration and dust suppression (Lemay, 1999). However, few of these technologies were accepted universally by producers due to high cost and/or high maintenance requirement. A simple and commonly adopted management to control odour is to maintain adequate setback distance from facilities and residence (Guo et al., 2005; Curran et al., 2002). The science-based setback distance is determined by air dispersion model which relies on source emission information (Zhu et al., 1998). Studies show that emission rates can vary with changes in the management of the animals, feed manipulation or weather conditions and may vary tenfold or more during periods as short as an hour or as long as a year. This variability in air emission rates is perhaps the most serious impediment to

generate a sound, reliable database (National Academy of Sciences, 2003). By now, there is no comprehensive data set on emissions from swine operations.

Some observations on diurnal emissions from piggeries found that diurnal pattern could vary during the daytime due to animal and worker activities (Hartung et al., 1998; Zhu et al., 2000; Sun, 2005; Groot Koerkamp et al., 1998). Significant variation of emissions between countries, between commercial houses and between seasons also occurred among studies (Groot Koerkamp et al., 1998). However, at present, none of the existing dispersion models consider the diurnal and seasonal variation of emission as data input. Under most circumstances, odour and gas emission rate that is more or less randomly measured for some specific time period at any time of the year without long-term monitoring has been used as input data for setback distance prediction. As a result, randomly measured emission data contribute to the great uncertainty of setback distance and it is difficult to finalize. Therefore, Schauberger (1999) suggested that long-term measurements of the odour release from livestock buildings were necessary to improve the application of the dispersion models and to calculate the separation distances necessary to prevent nuisance in the vicinity of the animal production enterprises. It is vital to obtain reliable measurements of air quality and emissions at large livestock building with inherently temporal variation of pollutants concentration so as to assess nuisance potential and set back distance (Heber et al., 2001). The calculated set back distance derived from field measurement is also needed to complement the limitation of field surveys. Furthermore, the seasonal and diurnal emission profiles also provide directions on further research on odour control and management of swine barn.

2 OBJECTIVES

The over-arching goal of this study is to monitor and model diurnal and seasonal odour, gases, greenhouse gases, and dust emissions from nursery, farrowing, and gestation rooms in Saskatchewan.

The first objective is to obtain the diurnal and seasonal profiles of odour, gas (ammonia, hydrogen sulphide), greenhouse gas (carbon dioxide, methane, and nitrous oxide), and dust emission from typical swine operations in Saskatchewan under different weather conditions as well as to reveal their relationship.

The second objective is to identify the relationship between odour and gas concentrations or emission rates with ambient temperature, indoor temperature, ventilation rate, animal unit, and pig density for different rooms.

The third objective is to quantify the contribution of greenhouse gas from different types of rooms to total emission from swine farms and to quantify the indoor air quality through the year for workers and animals.

The fourth objective is to establish a statistical prediction model of odour and gas emission as affected by sampling time, ventilation rate, building types, weather conditions, environmental parameters from nursery, farrowing and gestation rooms.

3 LITERATURE REVIEW

This part mainly deals with the previous findings on odour, gas and dust concentrations and emissions as well as modeling methods in different regions, barns and weather conditions. It provided basic characteristics of related research results and served as the reference of the studies.

3.1 Limitation of Existing Setback Distance Modeling and Air Dispersion Modeling Regarding Odour Emission

To address the odour nuisance problem, maintaining an appropriate setback distance between livestock operation site and neighbouring area is a widely practice in European countries, Australia and North America (Zhu et al., 2000; Guo et al., 2006; Lim, et al., 2001, Jacobson et al., 2006; Chaoui et al., 2007). The establishment or determination of setback distance can be accomplished from using guideline approaches or by the use of air dispersion models. However, the limitation is none of the existing models considered the diurnal and seasonal variation of odour source emissions (Guo et al., 2006). The variability of odour emission might cause great uncertainty of setback distance.

3.1.1 Setback distance models

The setback distance models are commonly referred to as setback guidelines which are Pgenerated by empirical formula or field surveys (Schauberger and Piringer, 1997; Guo et al., 2004). The widely accepted criteria for a setback distance based on the odour strength is 75 Odour Unit or above, or where the odour annoyance level is 2 on a scale of 0-5 (Guo et al., 2005). In the last two decades, some European countries (Austria, Germany, Switzerland, Netherlands etc.) and some states and provinces in North America (Ontario, Illinois, Purdue, Iowa, etc.) have developed setback guidelines (Lim et al., 2000; VDI 3471, 1986; VDI 3472, 1986; VDI 3473, 1994; CIGR, 1994). Austrian guideline is one of the typical models based on experience considering animal number, animal species, housing system, ventilation, the manipulation of manure etc.

(Schauberger and Piringer, 1997). Ontario MDS guideline models were calculated from some science-based information and a large quantity of personal experience (Guo et al., 2001). Williams and Thompson (1986) developed an empirical formula related the maximum setback distance from the source. They correlated odour emission with spatial extent of odour complaints. Purdue University developed an empirical model based on Austrian and Williams and Thompson models with additional consideration of building design and management, odour abatement, and outdoor manure storage factors (Lim et al, 2000). In Minnesota, Odour From Feedlots Setback Estimation Tool (OFFSET) was based on numerous odour emission measurements, INPUFF 2 model, and historical weather conditions to estimate the setback distance for different annoyance-free time (Jacobson et al., 2002). Since large differences existed in odour sources, manure handling methods, weather conditions, it is impossible to generate setback distance merely relied on anecdotal evidence or field sniffers.

3.1.2 Air dispersion models

The air dispersion models are robust tools that use specific odour emission, as well as meteorological and topographic data to predict the odour concentrations downwind, so as to determine the separation distance between animal sites and nearby residences. There are several models (e.g. ISCST3, ADMS3, AUSPLUME, INPUFF, and CALPUFF) that are available and adopted all over the world (US EPA, 1995a; US EPA, 1995b; US EPA, 2000). Most of the dispersion models were based on Gaussian dispersion theory which requires the source emission rate. In order to use the air dispersion model to predict odour appropriately, several issues should be addressed, e.g. the difference of odour and specific air contaminates, the instantaneous nature of odour, the relationship of odour concentration and intensity etc. (Guo, et al., 2006). Accurate model predictions for odour concentrations rely on accurate source emission data. So far, seasonal and diurnal odour emission variations have not been considered in odour dispersion models, which may result in great uncertainty in odour prediction and setback distance determination. To reduce the uncertainty of odour dispersion predictions,

seasonal and diurnal odour emission variations need to be considered in odour dispersion modeling.

3.2 Odour Emission Measurement

3.2.1 Previous research on odour concentration and measurement

Odours from animal operations contain many odorous compounds resulting from the anaerobic decomposition of manure (O'Neill and Phillips, 1992). Aerobic decomposition (decomposition in the presence of air) generally produces fewer odorous by-products than anaerobic decay, but aerobic decay can enhance volatilization of gaseous compounds that produce some odours and degrade environmental quality (Powers, 2003). Studies shown that odour from animal feeding operations is not caused by a single compound, but is rather the result of a large number of contributing compounds including NH_3, volatile organic compounds (VOCs), and H_2S (National Academy of Sciences, 2003). Odour emissions were different largely between countries, between commercial houses and between seasons (Koerkamp et al., 1998). Control of temperature and humidity may decrease generation and emission of odour and ammonia (Nimmermark et al., 2004). Ogink (2001) also found odour emissions from swine facilities fluctuated considerable with time.

Zhu et al. (2000) observed seven different animal facilities to determine daily variations in emissions of odour, ammonia, and hydrogen sulphide. In his experiment, air samples were collected every two hours over a 12-hour period during the day for odour and gas measurements. A nursery building had the highest emission rates for odour and hydrogen sulphide (max: 50 OU m^{-2} s^{-1} and 140 μg m^{-2} s^{-1}, respectively) and a naturally ventilated swine finishing building had the highest ammonia emission rate (max: 170 μg m^{-2} s^{-1}). There was no significant difference in average ammonia and hydrogen sulphide concentrations over 12-h sampling period for all the animal facilities. Ventilation rate played a key role in determining the emission rates of aerial pollutant from animal buildings. It was found that any activities taking place in the building during the sampling time would significantly affect the odour concentration and emissions.

Lim et al. (2001) evaluated two commercial swine nurseries in Indiana during the months of March, April and May. The nurseries were mechanically ventilated with long-term manure storage pits under wire floor. The mean odour emission rates of the two nurseries were 18.3 and 62.5 OU AU^{-1} s^{-1} respectively for one room is 19 years old with a pit exhaust fan and two wall fans and other room is 10 years old with one wall fan and one pit fan. No diurnal and seasonal variation was discovered in those studies.

Hartung et al. (1998) studied diurnal variation of odour emissions from two piggeries, one dairy house and two piggeries with biofilters for 24 h. Odour sample was collected every two hours between 0700 h and 1900 h and every three hours during the other time. The experiment discovered that odour emissions from the swine barn presented a pronounced diurnal pattern and could vary during the daytime due to animal and worker activities.

University of Minnesota conducted three years study to generate a large database on odour, total reduced sulphur (TRS), and NH_3 emission rates from 85 animal housing facilities and manure storage units. Statistical analysis indicated that specie and month of collection significantly affected odour and gas emission rates (Wood et al., 2001).

Sun (2005) reported his results on odour and gas diurnal and seasonal variation of grower/finisher rooms. He found that odour emission in rooms with fully slatted floor is 27.6 to 39.5% higher than that with partially slatted floor in diurnal measurement. For seasonal variation, the results significantly affected by the sampling month ($P < 0.05$), and no specific seasonal pattern was observed.

Guo et al. (2006) conducted one year odour emission measurements from two gestation,, two farrowing, four nursery, and three finishing rooms. The results showed that odour concentrations from all types of swine barns varied over the year ($P<0.05$), being high in winter and low in summer. Odour emission rates also varied significantly throughout the year but did not show specific variation pattern.

Moreover, many researchers attempted to explore the relationship between odour and H_2S or NH_3. No agreement was achieved among the studies. A number of studies (Verdoes and Ogink, 1997; Heber et al., 1998) have shown no correlation between ammonia and odour. Other also pointed out that hydrogen sulphide and ammonia concentrations are not correlated to livestock odour (Jannie, 2002). However, some studies have shown a correlation. From the measurements on a large number of farms in Minnesota a positive correlation (R^2=0.486) between odour and ammonia emission was found (Wood et al., 2001). Jongebreur et al. (2003) found that pig houses with low ammonia emissions also had low odour emissions.

3.2.2 Odour measurement method

Currently, the most common approach for measuring odour is olfactometry. It is a psychophysical method based upon the olfactory responses of trained panellists using an olfactometer, a dynamic, triangular, forced-choice dilution apparatus. The dilution to threshold is the number of dilution with odour-free air required for an odour to be perceived by 50% of the panel (ASTM, 1998). Commonly, it is expressed as odour units per cubic meter (OU m^{-3}). According to European Standard (CEN, 1999), the panellists were selected and re-evaluated periodically. Selected panellists will have sensitivity for n-butanol which falls between 20 and 80 ppb and also demonstrate consistency by achieving a low standard deviation in n-butanol threshold measurements. Olfactometry suffers from a lack of precision because of variations in human olfactory sensitivities. Even with its limitation, it is still the best techniques available to measure odour concentration. For this reason most of the studies on odour use olfactometry as the measurement method.

3.3 Ammonia and Hydrogen Sulphide Measurement

3.3.1 Previous research on ammonia and hydrogen sulphide measurement

The effect of ammonia on the environment arising from acidification and eutrophication could be severe. Agricultural sources, and livestock farming in particular, are the largest contributor to ammonia emissions. For example, 85% (over 220 000 t/yr) of the total

ammonia emission in The Netherlands originates from livestock farming (Anon, 1994). Ammonia from livestock husbandry is mainly from buildings, slurry and manure stores, pastures (grazing). Livestock housing and manure storage tanks contributed 40-60% of the total emission from livestock farming in these North European countries. Pig housing is mainly responsible (Koerkamp, 1998).

Ni et al. (1998a) measured H_2S and NH_3 from a 1000-pig mechanically-ventilated swine finishing building during a three-month study in Indiana. The 12.3 m by 65.9 m building had a 2.4 m deep pit under a fully slatted floor. The minimum H_2S and NH_3 emission rates were reported as 135 and 5.2 kg d^{-1}, respectively, while the maximum as 1882 and 36.2 kg d^{-1}, respectively.

Koerkamp (1998) measured ammonia emissions in livestock buildings in Northern Europe under summer and winter conditions. Mean ammonia concentration was between 5 and 18 ppm. The concentration of ammonia in a number of pig houses exceeded the threshold value of 25 ppm and may affect adversely the health of both stockmen and animals. Ammonia emission from pig house (sows, weaners and finishers) varied between 22 and 1298 mg/h per animal or 649 and 3751 mg/h (500kg) live weight. The emission rates should be used carefully due to large variations between countries, between commercial houses, and between seasons.

Heber et al. (2005) evaluated the characteristics of ammonia emission from two finishing buildings with three different flushing systems. The treated barn with soybean oil sprinkling resulted in 40% less NH_3 emission than the control barn. The mean NH_3 concentration and emissions were 17±8.5 ppm and 62± 22 g/d-AU.

Hayes et al. (2006) measured ammonia emissions at four intensive pig units in Ireland. The gas samples were measured close to the exhaust outlets of the ventilation system with a portable sensor. The mean ammonia emission rates were 12.1, 17.1, 1.4, 2.9, and 10.0 g d^{-1} $animal^{-1}$ for dry sows, farrowing sows, first stage weaners, second stage weaners and finishing, respectively.

3.3.2 Measurement method

For ammonia and hydrogen sulphide measurement, the simple and rapid method is to use the patches indicator and diffusion tubes (Wood, et al 2001). Patches are single use pieces of cardboard or plastic coated with a chemical that changes color when exposed to the gas being measured. Indicator tubes are glass tubes with both ends sealed. The media in the tube react and change color with select gases. The reading is taken by noting the amount of media that reacted with the gas. Diffusion tube has the same principle as the indicator which gives the average concentration. This method has low accuracy of up to 30% of uncertainty; therefore, it may not meet the accuracy requirement of most studies. Jerome meter, MDA single-point monitor, electronic nose and Gas chromatograph/mass spectrometer are the common techniques for gas analysis. When reporting gas concentrations, it is essential to specify whether the results are instantaneous or average values.

3.4 Greenhouse Gas Measurement

The Kyoto Protocol has been adopted since 1997 in the United Nations Framework Convention on Climate Change. The protocol targets six different greenhouse gases (GHG): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), HFCs (hydrofluorocarbons), PFCs (perfluorocarbons) and SF_6 (sulphur hexafluoride) that are determinant in the global warming phenomenon (Grubb et al. 1999). Grubb et al. (1999) reported that CO_2, CH_4, N_2O accounted for almost 99% of the total GHG emission. Once these three GHG emitted to the atmosphere, the lifetime will last 100, 12 and 120 years for CO_2, CH_4 and N_2O, respectively. According to Environment Canada (2003), the total GHG emissions from the Canadian livestock sector have increased from 24, 270 kt of CO_2 equivalent in 1990 (41% of the total agricultural emissions) to 28,900 kt of CO_2 equivalent in 2001 (48% of the total agricultural emissions). It is necessary to quantify the GHG emission from the swine barns to determine its contribution to the GHG emission in the agricultural sector. It is estimated that one third of the methane produced each year comes from industrial sources, one third from natural sources and one third from agriculture, primarily animals and manure storage units (Powers, 2003).

Laguë et al. (2004) experimentally determined the GHG emission from four commercial liquid manure storages using the open chamber technique during the spring to fall period between 2001 and 2003. On average, methane and carbon dioxide emission rates were 2.41 g CO_2 equivalent day^{-1} kg^{-1} (kg of animal mass) and 0.94 g CO_2 equivalent day^{-1} kg^{-1}(kg of animal mass), respectively, while nitrous oxide emission rates were negligible. They estimated that the addition of a blown on chopped straw cover on an earthen manure basin can yield reductions in CO_2 and CH_4 emissions of 34 and 382 tonnes of CO_2 equivalent per year, respectively, for each 1,000-sow increment.

Peu et al. (1999) developed a floating open chamber system to measure N_2O emissions from the surface of liquid manure storage or manure treatment facilities. During a two-month period, they measured N_2O emissions ranging from 79 to 91 mg h^{-1} m^{-2} at the surface of an aerated liquid pig manure storage facility. Husted (1993) evaluated the feasibility of using an open chamber technique for measuring CH_4 emissions from either liquid or solid pig manure storage facilities. Daily emission rates varied between 0.5 to 49.8 g day^{-1} m^{-3} for liquid manure storages (over a 19-day period during the spring) and 17.9 to 92.0 g day^{-1} m^{-3} for solid manure storages (over a 31-day period during the summer). Roger Phillips et al. (1997) measured CH_4 emission rates ranging from 0.014 to 0.39 g day^{-1} m^{-3} of stored manure over different types of manure storage facilities. Husted (1994) reported CH_4 emissions from manure storage facilities of 5.9 (solid cattle manure), 8.2 (cattle slurry), 11.6 (pig slurry) and 28.3 (solid pig manure) g day^{-1} m^{-3}. Several studies reported that N_2O emission is insignificant from livestock facilities (Laguë et al., 2004; Roger Phillips et al. 1997).

Zhang et al. (2007) measured greenhouse gas on two 3000-sow swine farrowing, one with open earthen manure storage (EMS) and another with negative air pressure (NAP) covered EMS. A wind tunnel was used to collect air samples from the manure surface in the open EMS. The CO_2 emission rates from exhaust buildings ranged from 4.8 to 16.6 kg d^{-1} AU^{-1} and the rate from farrowing rooms was significantly higher than that from gestation room. The CH_4 emission rates from the building exhaust ranged from 73 to

351 g d^{-1} AU^{-1}. Both CO_2 and CH_4 emissions from the secondary cell of the NAP EMS were negligible in comparison with the primary cell or with the open EMS.

Most of the research was conducted with the manure storage. Little has been done to quantify greenhouse gas emissions from animal barns. Osada et al. (1998) measured CO_2 from pig units. It presented a typical diurnal fluctuation pattern. At a constant indoor temperature of around 17°C, the CO_2 emissions observed at the peak hours (1300-1400 h) was twice as high as that observed around 0600 h. The CO_2 emission from pig units during a full 8-week finishing period was evaluated to 5540 g pig^{-1}. It was also observed that the increase in CO_2 production might also have some relationship with the pig excreting activities (Osada et al., 1998).

3.5 Ventilation Rate Measurement

Ventilation rate plays a key role in emission determination (Zhu et al., 2000; Zhou et al., 2003). The existing methods can be categorized into two ways involving direct and indirect methods. Fan method and velocity traverse method could be grouped into direct measurement while carbon dioxide mass balance, heat balance, and tracer gas methods belong to indirect measurement (Zhu et al., 2000; Heber et al., 1997, Phillips et al., 2001; Albright, 1990). To obtain an accurate ventilation rate is difficult because it could be easily affected by fan running condition, dust build up and power supply variations (Bicudo et al., 2002). It was estimated that fan method could have an uncertainty up to 15% (Guo et al., 2006). By now, fan method and carbon dioxide mass balance are two common methods that are adopted to calculate mechanically ventilated buildings and naturally ventilated or "hybrid" buildings, respectively (Sun, 2005). Fan method is to estimate the airflow rates from fan performance testing report which need to know vacuum pressure in the room and fan rotation speed. The equation of ventilation rate based on carbon dioxide mass balance is as follows:

$$V = CO_2\,production \times 10^6 / \left((CO_2)_o - (CO_2)_i \right) \tag{3.1}$$

where

$CO_2 production$ is the carbon dioxide production rate in the room, $m^3\ h^{-1}$;

$(CO_2)_o$ is the exhaust carbon dioxide concentration, ppm; and

$(CO_2)_i$ is the incoming carbon dioxide concentration, ppm.

3.6 Dust Measurement

3.6.1 Previous research on dust

Dust is a major concern in air quality within the livestock buildings that adversely affect the potential health safety of workers and animals themselves (Donham, 1986; Curtis et al., 1975; Crook et al., 1991). It was reported that over 60% of the workers experienced adverse reactions after working in the barns for a long duration (Donham et al., 1977). Dust is also an important carrier of odour (Hoff et al., 1997; Day et al., 1965). Odorous compounds adhere to dust particles and removal of dust can reduce the odour in air from swine houses by 65% or more (Hoff, 1997). Dust in livestock buildings is generated mainly from feed, bedding, dried feces, and animal skin and hair (Maghirang et al., 1995). Factors determining the amount of dust include cleanliness of the houses, animal activity, temperature, relative humidity, ventilation rate, and stocking density.

Kim et al. (2005) conducted an experiment on temporal and spatial distributions of aerial contaminants in an enclosed pig barn in winter. It was observed the concentration of total dust and total airborne bacteria had a significant correlation with temperature and relative humidity (P<0.05). There were significant correlations between total dust and total airborne bacteria, between total dust and ammonia, and between total dust and odour at the 95% confidence level. Barber et al. (1991) also conducted an experiment to assess the spatial variability of dust within an occupied piggery. Aerial dust samples were collected every 24 h and settled dust samples every 4 days. The mean aerial dust concentration was 2.2 mg m^{-3}, ranging from 1.6 to 2.74 mg m^{-3}. The mean dust sedimentation rate was 137 mg $m^{-2}\ h^{-1}$, varying from 70 to 295 mg $m^{-2}\ h^{-1}$. Chang et al. (2001) used filter-weight method to quantify the dust concentration on six farms. Mean concentration of total dust was between 0.15 and 0.24 mg m^{-3}, with average level of respirable dust of 0.14 mg m^{-3}. They found that the total dust in the nursery house was

higher than that in breeding and finishing rooms. The breeding barns had the lowest level of dust. It is recommended that frequent spraying water inside the stalls can significantly reduce accumulation of gases and airborne particulates. Robertson (1998) reported the dust concentration over a single 24 h period from a survey of 12 commercial pig farms in Scotland ranging from 1.05 to 18.60 mg m^{-3} for the mean total dust concentration in individual rooms.

The above mentioned results showed clearly that the dust concentration varies widely from study to study. It is reported that animal activity, type of ventilation, and type of housing system are important for generation of dust and sprinkling with water or oil in barn is effective to reduce dust concentrations (Gustafsson, 1999). Since sprinkling decreases dust concentration and since humidity seems to be important for odour, a correlation between dust and odour might exist.

3.6.2 Dust measurement method

The measurement of dust concentrations in and near animal facilities is typically performed using gravimetric methods. This is accomplished by weighing a collection filter before and after a known quantity of sample air passing through the filter inside or near the animal unit. The results are generally given in unit of mg of dust per cubic meter of air (mg m^{-3}). Certain filters are designed to collect all of the dust and are reported as total dust concentrations, while a certain device collects only particles small enough to enter the human respiratory system, which are reported as respirable dust.

Another method of dust measurement is electronic particle counters. These devices report the number (not mass/weight) of particles per volume of air (number of particles m^{-3}). Often these instruments can categorize dust into particle diameter, which is beneficial in assessing livestock, poultry, and human health risks.

Dust may also be measured by depositing the particles on a piezoelectric sensor by electrostatic precipitation. The rate of change of the resonant frequency of the sensor is directly proportional to the mass of material deposited on it.

3.7 Modeling

When applying the odour emission rate to the odour dispersion model, researchers have made an assumption that odour release from livestock building without a diurnal and seasonal variation, which gave a crude approximation to the odour dispersion. It may account for the large uncertainty of several dispersion models for predicting the downwind odour concentrations (Schauberger et al., 1999).

Schauberger et al. (1999) determined an odour emission model by combining a steady-state sensible heat balance model to calculate the exhaust air temperature and the air exchange rate:

$$S_a + S_b + S_c = 0 \qquad (3.2)$$

where:

S_a is the sensible heat release of the animals;

S_b represents the loss of sensible heat caused by the transmission through the building;

S_v is the sensible heat flow caused by ventilation.

Both the ventilation rate and odour emission rate are functions of outside temperature. The meteorological data is implemented as the input to calculate the odour emission. It showed that a distinct diurnal and annual variation of the odour concentration due to the variability of the ventilation rate. The model predicted that the night time odour concentration is 4.6 times of the daytime concentration due to the reduced ventilation rate at night (Schauberger et al., 1999). Therefore, the authors suggested actual measurements should be conducted to validate the odour emission rate model and diurnal and seasonal monitoring was necessary to optimize the use of air dispersion models.

Sun (2005) developed linear statistical models for each type of the flooring system to determine odour and gas concentration and emission rate based on the room and ambient temperatures, the ventilation rates and the animal units. The predicted results showed good agreement with measured values for most of measurements (R^2= 0.67-0.95)

Researchers initially attempted to determine a single-component of the odour that could act as an indicator for odour intensity (Lunn et al., 1977; Williams, 1984). Zahn et al. (2000) developed a nine component statistical model of the odour emission. However, as we know, swine odour is very complex and it has over 200 different components that may interact with each other. A variety of factors contribute to the generation of the odour, such as relative humidity, temperature, feed manipulation, manure management (Schiffman et al., 2001; Zhang et al., 2002.) It is insufficient to just use single-component to qualify the livestock odour. Janes et al. (2005) used multiple-component multiple-factor analysis and neural networks to predict the odour concentration or intensity. First, a neural network model and a linear multiple regression model are developed and compared using multiple-component analysis to demonstrate the better modeling technique for the swine odour. The neural network model of the swine odour yielded more accurate and precise odour intensity predictions than the linear multiple regression models, indicating that neural networks are a better modeling technique for this application. Subsequently, a multiple-component multiple-factor neural network model was developed and compared with the multiple-component neural network. This study suggested that odour components and generation factors (outside temperature, time of day, time of year) in the modeling process combined with intelligent modeling techniques will provide performance advances over conventional multiple-component statistical odour models.

4 MATERIALS AND METHODS

This project was conducted at PSC Elstow Research Farm Inc., located near Elstow, 50 km away from Saskatoon, Saskatchewan, Canada. The experiment commenced in August, 2006 and was completed in July, 2007.

4.1 Description of Study Facilities

For this study, a nursery room (nursery room 5), a farrowing room (farrowing room 5), and a breeding/gestation room with individual stalls were selected as the study subjects. All three rooms were ventilated mechanically by wall exhaust fans which were controlled by integrated environmental control systems (Model-Supra, Phason Inc., Winnipeg, Manitoba, Canada). The nursery room and farrowing room located opposite to each other across the hallway, with identical sizes and fully slatted floors. In the nursery room, there were 3 fans and 16 pens with 16 pigs per pen. The farrowing room had 2 exhaust fans and 14 crates. The gestation room had 10 exhaust fans and partially slatted floors. The fresh air is supplied into the experimental room through inlets in the ceiling. The manure storage pits beneath the slatted floors of all three rooms were 3 feet deep. Manure pits collected the slurry and were pumped out to the earthen manure basin periodically, every 8 weeks for the nursery room and 3 weeks for both farrowing room and gestation room. All three rooms were equipped with nipple drinkers and nursery and gestation pigs were fed by automatic feeder, while farrowing pigs were fed manually. The detail description of experimental rooms were presented in Table 4.1.1

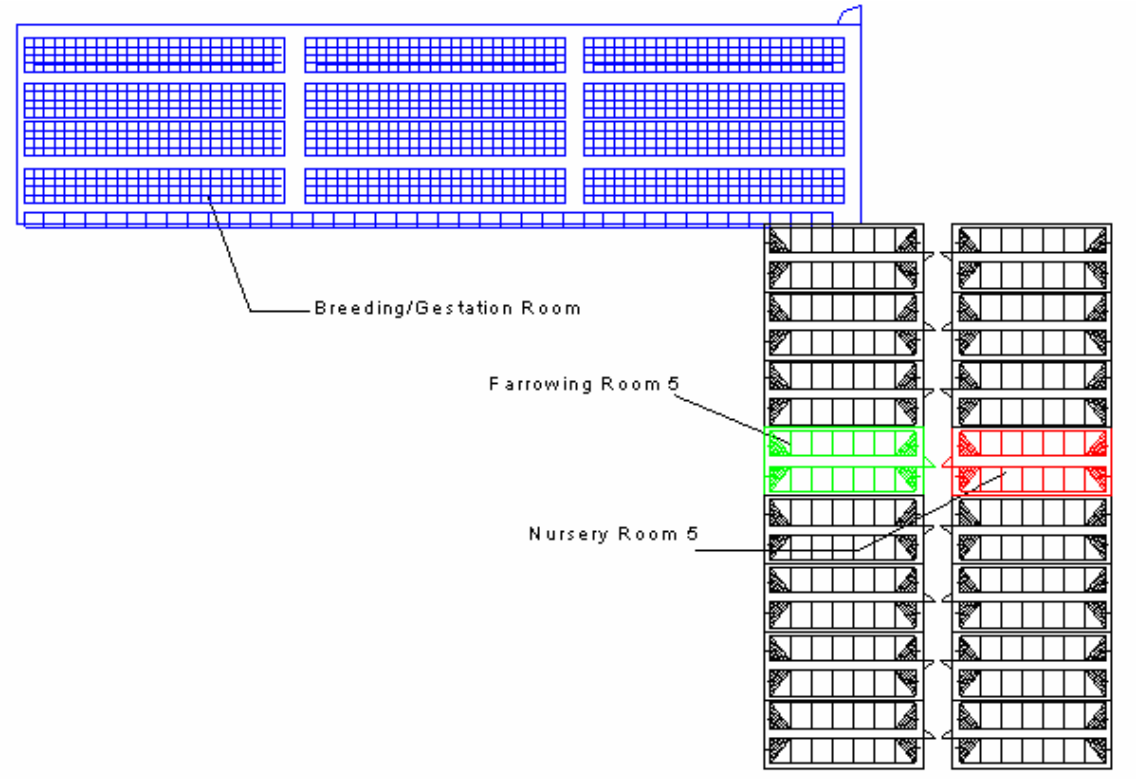


Figure 4.1.1 Layout of experiment building

Table 4.1.1 Basic information of swine rooms

Facility	Floor type	Size (leng×width,area)	capacity (No.)	Fan (No.)	Feed type	Manure removal (week)
Nursery	Fully slatted	14.9×7.2m (107m^2)	256	3	Automatic	8
Farrowing	Fully slatted	14.9×7.2m (107m^2)	14	2	Manual	3
Gestation	Partially slatted	57.5×15.2m(874m^2)	416	10	Automatic	3

4.2 Experimental Design of Odour and Gas Measurement

4.2.1 Experimental design of diurnal measurement

The purpose of diurnal measurement was to obtain the diurnal profile of odour and gas concentrations and corresponding emission rates under different climatic conditions. Saskatoon climate normals from 1971-2000 of 30 year period was given in the following Table 4.2.1

Table 4.2.1 Saskatoon Climate Normals 1971-2000 (Environment Canada, 2007)

Month	Temperature (°C)				Relative humidity (%)
	Daily Mean	S.D.	Daily Max	Daily Min	Daily average(1500 LST*)
Jan	-17	4.8	-11.8	-22.3	70.9
Feb	-13	4.6	-7.8	-18.2	72.1
Mar	-5.8	3.7	-0.7	-10.9	67.8
Apr	4.4	2.4	10.6	-1.9	48.7
May	11.5	1.8	18.4	4.5	42.2
Jun	16	1.5	22.6	9.4	47.3
Jul	18.2	1.3	24.9	11.4	48.8
Aug	17.3	2	24.4	10.2	45.6
Sep	11.2	1.8	18	4.4	46.9
Oct	4.5	1.4	10.8	-1.9	50.4
Nov	-6.2	3.6	1.5	-10.9	68.8
Dec	-14.3	4.5	-9.2	-19.3	71.9

* LST stands for Local Standard Time

According to Table 4.2.1, the weather condition of Saskatoon can be categorized into three groups, warm climate (May, June, July, August, and September), mild climate (April and October), and cold climate (January, February, March, November, and December). In order to characterize the representative diurnal profile of odour and gas emission rates, three months (February, April and August) were chosen as the typical cold, mild and warm condition of the year.

For statistical requirement, sufficient replication is necessary to get an acceptable result. However, odour sampling and quantification is a time-consuming and expensive procedure (over $100 per sample). Balancing these two aspects, the strip-block experimental design was applied. Replication was carried out by collecting the samples in two consecutive days in each of the three selected months. In each measurement day (known as the block), two factors “room type” and “diurnal” were considered. Factor “room type” was defined as the main plot factor with three levels, including nursery room, farrowing room and gestation room, respectively. Factor “diurnal” was treated as the function of ventilation rate, room, ambient temperature, cleanliness of the room, and management. For the diurnal level, 8 levels were determined according to previous research experience (Sun, 2005). Therefore, odour and gas (including ammonia,

hydrogen sulphide, carbon dioxide, and greenhouse gases) were sampled every 3 hours by continuously pumping the air into two identical sampling bags, 8 sampling periods per day. A total of 16 paired samples were collected during the two consecutive days for each room. The 3-h average concentrations were measured. For each paired samples, one was used for odour concentration measurement and the other for gas concentration measurements. Thus, the diurnal experiment was assigned as 2- factorial repeated design with 24 treatments. The SPSS repeated measure analysis was used to layout the experiment design. The detailed layout of diurnal strip-block was tabulated in Table 4.2.2

Table 4.2.2 Source of variation and degrees of freedom for strip-block design

	Day 1 (Block 1)			Day 2 (Block 2)		
	Room type			Room type		
	Nursery	**Farrowing**	**Gestation**	**Nursery**	**Farrowing**	**Gestation**
Time of the day	0600-0900	0600-0900	0600-0900	0600-0900	0600-0900	0600-0900
	0900-1200	0900-1200	0900-1200	0900-1200	0900-1200	0900-1200
	1200-1500	1200-1500	1200-1500	1200-1500	1200-1500	1200-1500
	1500-1800	1500-1800	1500-1800	1500-1800	1500-1800	1500-1800
	1800-2100	1800-2100	1800-2100	1800-2100	1800-2100	1800-2100
	2100-2400	2100-2400	2100-2400	2100-2400	2100-2400	2100-2400
	0000-0300	0000-0300	0000-0300	0000-0300	0000-0300	0000-0300
	0300-0600	0300-0600	0300-0600	0300-0600	0300-0600	0300-0600

For the ammonia (NH_3), hydrogen sulphide (H_2S) and carbon dioxide (CO_2), besides the average 3-h concentrations, hourly concentrations were also recorded by an automatic sampling system. Forty eight (24 samples/day ×2 days) data were collected per room for each diurnal measurement. The statistical analysis of variance table was outlined as follows:

Table 4.2.3 Source of variation and degrees of freedom for strip-block design

Source of Variation	Degrees of Freedom
Blocks(day)	1
Room type(A)	2
Error (E_a)	2
Diurnal(B)	7
Error (E_b)	7
Room type×Diurnal (A ×B)	14
Error(E_c)	14
Total	47

Error a obtained for the factor A (room type), error b obtained for the factor B (diurnal), while error c was for interaction effect of AB. Thus there will be three mean square errors applicable for testing the significance of main effects of factors and their interaction. If the *P*-value is less than α=0.05, then we would reject the null hypothesis and consider that the factor had significant effect on the measured variables. If *P*-value is larger than α=0.05, we can accept the null hypothesis that there is no big difference within the factor level. For the interaction effect, a p-value less than 0.05 indicated that interactive effect existed between the two factors and the observation was influenced by fixing one factor level and changing the level of the other factor. If there was interaction effect, it is appropriate to use the post-hoc method such as Duncan multiple range test to compare the response of one factor within each level of the interacting factors.

4.2.2 Experimental design of seasonal measurement

The purpose of seasonal monitoring is to obtain odour and gas concentrations and emission rate profiles in the annual course. Hence, 2 factorial experiment design was introduced: “room type” factor with 3 levels and “month” factor with 12 levels. The air samples were collected around the 20th of each month from August 2006 to July 2007 over a period of 12 months. During the monthly measurement, 2 identical samples were collected from each room during 0900-1200 h periods when the pigs had high activity.

In the statistical analysis, factor "room" type was treated as main factor, and measured months were treated as sub-factor. The model describing the relationship of independent factor and dependent factor can be expressed in Table 4.2.4.

Table 4.2.4 Source of variation and degrees of freedom for odour seasonal measurement

Source of Variation	Degrees of Freedom
Room type	2
Month	11
Room type ×Month	22
Error	36
Total	71

For NH_3, H_2S, CO_2 measurement, in order to get a more detail picture of seasonal variation, these three parameters were sampled hourly for three successive days by an automatic sampling system. Therefore, 72 data points (24 data/day × 3 days) for each gas per room were obtained.

General linear model (GLM) procedure in SPSS was conducted to evaluate if odour and gas concentration and emission rate were statistically significantly affected by seasonal variation and if there is difference among three types of rooms. If *P*-value of the interaction effect between month and room greater than $\alpha = 0.05$, it demonstrated that there was no difference between room types in each sampling month and we can compare the month variation regardless of room type. However, if *P*-value of the interaction factor less than $\alpha = 0.05$, it means the significant interaction existed and we have to analyze the seasonal variation of odour and gas from each room separately.

4.3 Odour and Gas Measurement

4.3.1 Definition of emission rate

Emission rate (E) was defined as the products of odour or gas concentration difference (ΔC) between supply air and exhaust air, and the total ventilation rate of a room (V).

$$E = V\Delta C \qquad (4.1)$$

where:

E is the total odour or gas emission rate from a room, in unit of OU s^{-1} (Odour Unit per second), g d^{-1} (gram per day), or kg d^{-1} (kilogram per day);

V is the room ventilation rate, m^3 s^{-1}, and

ΔC is the difference in odour or gas concentrations between exhaust air and the supply air of a room, in unit of OU m^{-3} (Odour Unit per cubic meter), or g m^{-3}, or ppm (parts per million).

It was found that different emission rate units were used by previous studies. Some researchers used emission rate on per animal unit basis (1 AU = 500 kg of live mass of animals) by dividing the total emission rate per room by the total animal units in the room, i.e. OU AU^{-1} s^{-1} (Odour Unit per animal unit per second) for odour and g AU^{-1} d^{-1} (gram per animal unit per day) for gas. While some preferred to express on per unit building floor area basis that is derived from dividing the total emission rate by total flooring area, i.e. OU m^{-2} s^{-1} (Odour Unit per square meter per second) for odour and g m^{-2} s^{-1} (gram per square meter per second) for gas. Allowing for standardizations and comparison with other studies, the odour and gas emission rates in this study were reported in both ways.

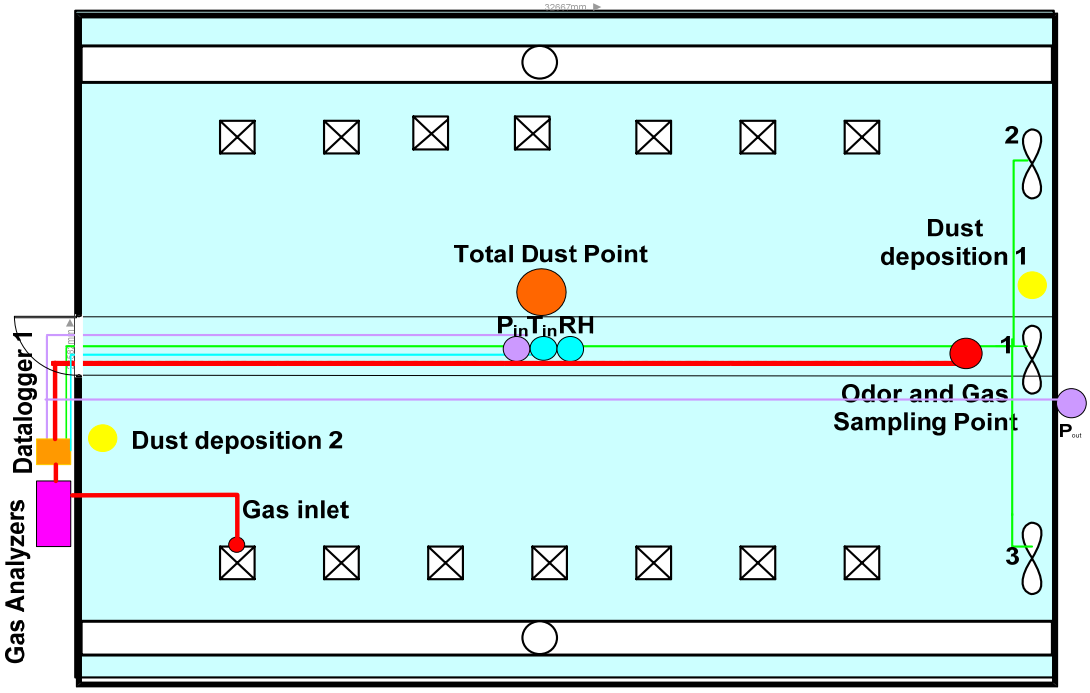
4.3.2 Odour concentration measurement

As shown in Figure 4.3.1, circles shaded with red symbolize the odour and gas sampling points near the exhaust fans. There was only one sampling point in the alley of the room close to exhaust fans for nursery and farrowing room. Whereas there were two odour and gas sampling points in the gestation room because of its large floor area. The two sampling lines merged into one line in the middle of the room, which was the mixture of the exhaust airs from the two sampling points and represented average exhaust air. Thick lines in the figures were the Teflon tubing which could eliminate the residue of odour and gas along the inner surface of the tubing and improve the sampling accuracy. There were two Teflon tubing at the odour and gas sampling point in each room, one odour tubing, and the other gas tubing. The odour tubing was used to take samples for the average 3-h odour concentration and average 3-h gas concentration. The gas tubing was used to take samples for hourly gas concentration. For 3-h sampling, exhaust air

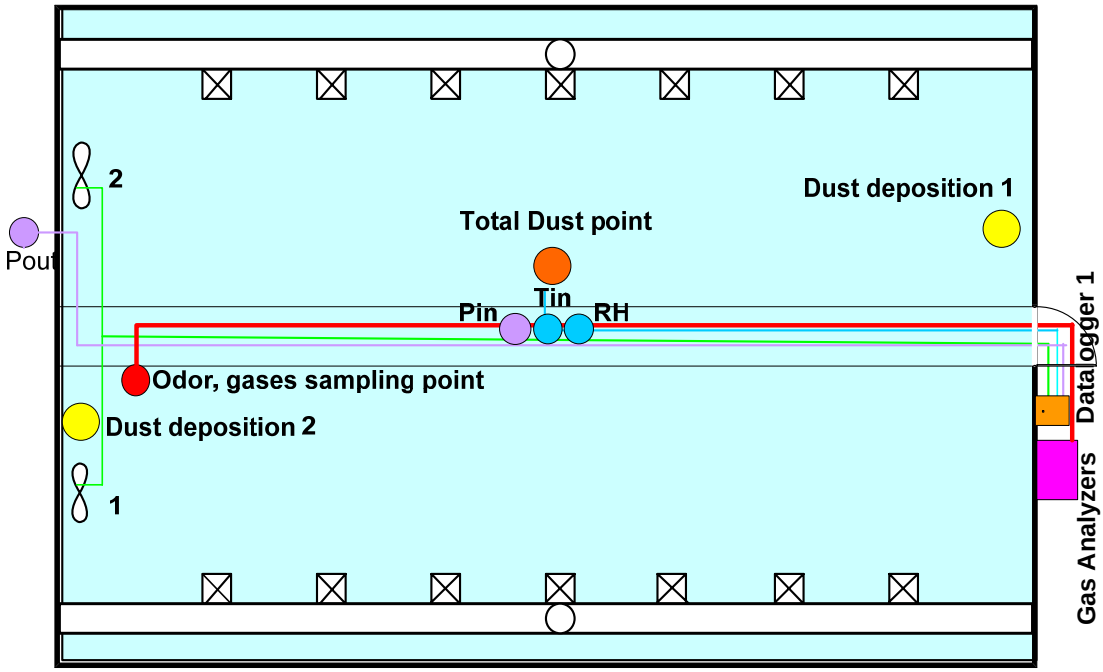
were drawn into two identical bags through a peristaltic pump (Master flex L/S tubing pump plus Model 7017-52 pump head, Cole-Parmer, Vernon Hills, USA) at a rate of 0.05 L/min continuously for 3 hours, which represented average 3-hour concentration. The pumps were set up outside of each room and attached to two 0.05 mm thick; 10 L Tedlar sampling bags (SKC, Inc., Eighty Four, USA). Before collecting air samples, the bags were pre-flushed by pumping 2 to 3 L of the sample air in the bags and then emptied the bags manually. For diurnal measurement, two identical air samples were collected, one for average 3-h odour measurement while the other for average 3-h gas measurement. For the seasonal measurement, all two samples were used for odour measurements. It is also noted that filter were installed in the cassettes and attached to the end of odour and gas tubings to avoid dust getting into the tubings.

The odour sample bags were shipped to the olfactometry laboratory for measurement within 30 hours after the samples were collected. Odour samples were assessed by trained panellist with a triangular dynamic forced-choice olfactometer in Olfactometry Laboratory, University of Alberta, Edmonton, Alberta, Canada. The procedure conformed to the CEN (European standard) and ASTM olfactormetry standards protocol (CEN, 1999, ASTM, 1998). Eight screened odour panellists were presented the mixture of odour sample and known amount of odour-free air. Odour concentration was defined as the dilution ratio at detection when 50% of the panel perceived the odour. The odour concentration of a sample is expressed as odour units per cubic meter (OU m^{-3}) for calculation of odour emission rate (CEN, 1999).

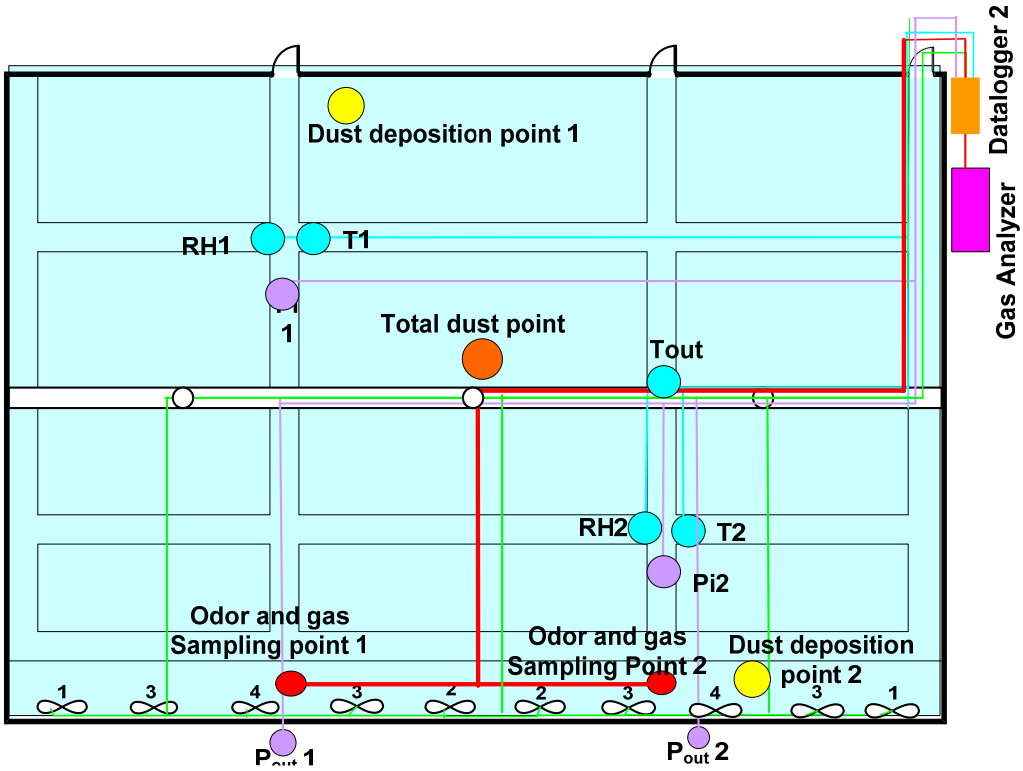
The odour concentration of inlet air was generally very low as compared with the exhaust air from the building. Weak odour samples are hard to be detected using dynamic olfactometry (Miller, 2004); therefore, the inlet concentration of odour was assumed to be negligible.



(a) Nursery room



(b) Farrowing room



(c) Gestation room

Figure 4.3.1 Layout of sampling locations in three rooms

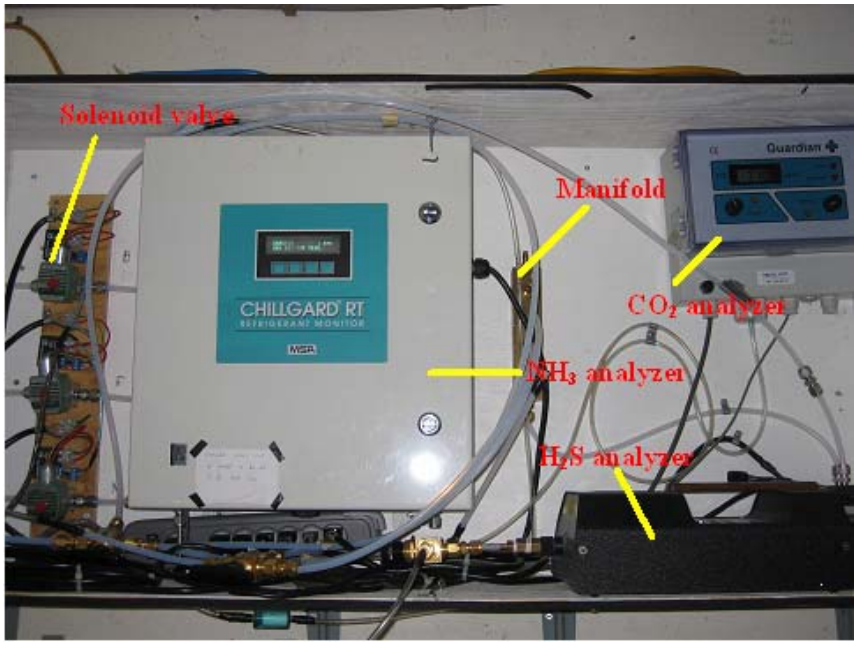
4.3.3 Gas concentration measurement

4.3.3.1 Automatic sampling system

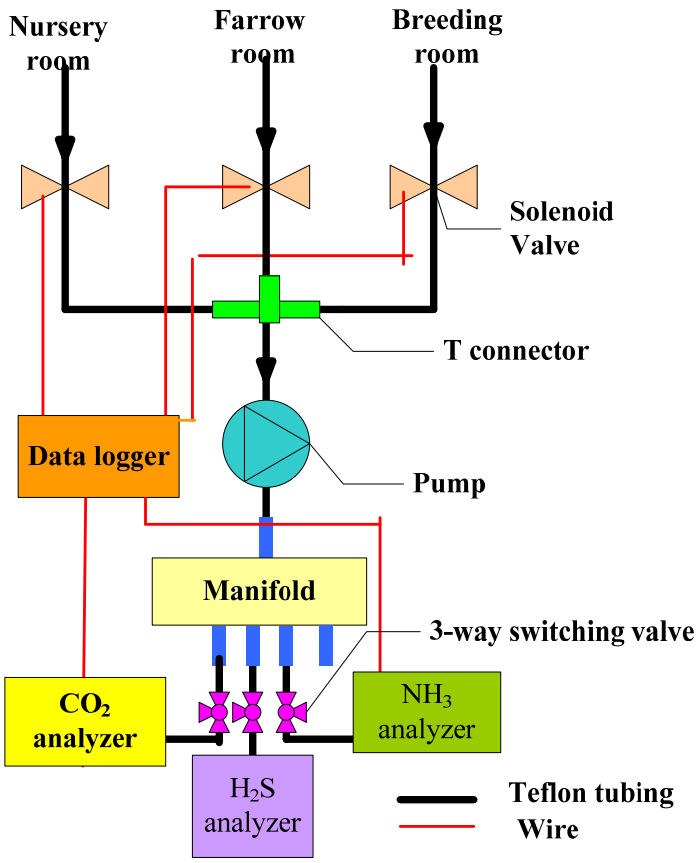
Long-term continuous data collection was deemed very important because of inherently high spatial and temporal variance of gas concentrations (Kim et al., 2005). Long-term hourly gas concentration profile can provide a detailed picture of concentration variation and reduce the uncertainty due to random measurement. Hourly gas concentrations (NH_3, H_2S, and CO_2) were detected by an automatic gas sampling system. Figure 4.3.2 illustrated detail components of the system and on-site prototype. The gas sampling system consisted of three solenoid valves (8016G, ASCO Valve Canada, Brantford, Ontario, Canada), one air pump, a manifold and infrared NH_3 analyzer (CHILLGARD RT refrigerant monitor, ±2% accuracy, MSA Instrument Division, USA), H_2S analyzer (JEROME 631-X, with accuracy of ±0.003 ppm at 0.05 ppm, ±0.03 ppm at 0.5ppm and ±0.3 ppm at 5 ppm, Arizona Instrument Corporation, Phoenix, AZ, USA), and CO_2

analyzers (Guardian Plus Infra-Red Gas Monitor,±2% accuracy, Edinburgh Sensors Limited, Hingham, MA, USA). The manifold was made of brass built by Engineering Mechanical Workshop, College of Engineering, University of Saskatchewan. It had one inlet and four outlets, three of them were connected to three analyzers respectively by Teflon tubing, while the fourth outlet was designed for deflating.

Figure 4.3.2 (a) was the experimental setup and (b) was the schematic flowchart of this system. Air was analyzed by sequential switching of solenoid valves between three rooms on 5 min sampling intervals. The switch was controlled by a data logger (CR 10X, Campbell Scientific Corporation, Logan, USA). When the data logger sent out a signal to the solenoid valve, one valve kicked off. Air was pumped continuously through gas tubing from inside of one room. Then the air flowed through solenoid valves and air was pump into the manifold. The function of the manifold was to split the air into three analyzers. All the three analyzers had their own inner pumps and can draw the air in the manifold into their sampling parts. Each room was continuously measured during a 5-min sampling period before switching to the next room. Because of the long distance from remote location to the gas analyzers as well as possible surface absorption of gases or residue by the sampling tubing and manifold from previous sampling, the first four minutes of pre-equilibration data during each 5 min sampling period were discarded. Gas concentration readings were averaged over the last minute representing the period mean gas concentration. After 5 minutes, one room measurement was completed and the second solenoid valve was activated. Therefore, three room gas measurements can be conducted in a 15-min cycle. In one hour, each room can be measured four times and hourly concentration value then be obtained by averaging the four measurement data.



(a) Experimental setup



(b) Schematic sampling system

Figure 4.3.2 Experimental setup and schematic automatic sampling system

The gas measurement techniques and sensors described above were chosen for their ability to measure continuously and automatically, and for their reliability, stability, precision and insensitivity to humidity, especially compared to less expensive electro-chemical sensors. Because the environment where the analyzer worked was rather harsh and to ensure the accurate measurement, the NH_3 analyzer was calibrated before each diurnal measurement and H_2S analyzer was sent to the manufacture for calibration after 6-month operation. Readings in NH_3 and CO_2 analyzers were both displayed by LCD screen. In order to record data by the data loggers, the output should be converted into analog signal. Specific resistances were connected to the analyzer's output to get a voltage output which was applicable for the data logger. The relationship between real value and voltage output were established before testing. The H_2S Jerome meter had its own data logger.

For CO_2 concentration measurement, when the concentration was lower than 3000 ppm, it was measured directly by the automatic gas sampling system. However, CO_2 concentration over 3000 ppm in winter exceeded the limit of the CO_2 analyzer in the automatic gas sampling system, therefore there was no hourly CO_2 concentration for some winter months. When CO_2 exceeded 3000 ppm, average 3-h concentration was obtained using the air samples collected for 3-h odour and gas measurement by the Gas Chromatography Laboratory, Department of Soil Science, University of Saskatchewan

Inlet gas sampling point was located in the inlet of the nursery room (small circle shaded with red in Figure 4.3.1 (a)). The purpose of inlet gas concentration measurement was to obtain the incoming air CO_2 concentration. It was sampled twice during each monthly measurement, one before measurement, another after the measurement. The inlet concentrations of NH_3 and H_2S were very low and assumed zero.

4.3.3.2 Greenhouse gas measurement

Greenhouse gas measurement involved methane (CH_4) and nitrous oxide (N_2O) besides carbon dioxide (CO_2) that was already measured together with other gases. The gas

samples were collected from gas sample bags by injectors and stored in 10 ml vacuum tubes. They were measured in the Gas Chromatography Laboratory, University of Saskatchewan. All the greenhouse concentration values represented average 3-h concentrations, the same as odour concentrations.

4.4 Ventilation Rate Measurement and Verification of Fan Flow Rate

4.4.1 Ventilation rate measurement

Fan characteristics and performance information is displayed in Table 4.4.1. All fans were variable-speed fans except for TR36TP which is a single speed fan (Prairie Pride Enterprises, Winnipeg, MB, Canada). Ventilation rate was determined using the fan method, i.e. by measuring the vacuum pressure in the room and rotating speeds of all the operating fans including variable and single speed fans. Fan testing report from Bioenvironmental and Structural System Laboratory, Department of Agricultural Engineering, University of Illinois (2001) was used to estimate the airflow rate. The calculation of airflow rate was shown in Appendix B. The total ventilation rate of a room was the sum of the airflow rates of all fans.

Table 4.4.1 Fan characteristics and performance information

Room type	No.Fans	Fan stages	Fan model	Capacity
Nursery	3	stage 1	TR16F	2469
		stage 2	TR20F	4160
		stage 3	TR20F	4160
Farrowing	2	stage 1	TR12F	1405
		stage 2	TR20F	4160
Breeding	10	stage 1	TR 24F(2)	5500
		stage 2	TR 24F(2)	5500
		stage 3	TR36TP(4)	11300
		stage 4	TR36TP(2)	11300

Note:Numbers in parenthesis indicate number of fans of the same stage

A differential pressure sensor (Model 265, accuracy of ± 1% full span, Setra System Inc, Boxborough, MA, USA) was utilized to measure the static pressure differential between the outside and inside of each room. The pressure lines consisted of two 6.35 mm ID Tygon tubing. The inlet of one tubing was placed in the middle of the room 1.5 m above

the floor. The inlet of another tubing was placed in the outside facing ground to prevent wind interference and ice build up in the tubing.

Fan rotating speeds (RPM) were detected by micro switch Hall Effect position sensor (SR3F-A1, Honeywell Inc., Freeport, Illinois, USA). The sensors were mounted on the motor of the fan and obtained the fan speed by sensing the magnetic field changes that was generated by the magnet glued on the surface of the hub. The output of the sensor was a frequency signal. Electronic circuit boards were developed to transmit and track the records. Figure 4.4.1 presented the schematic working principles for fan rotation speed measurement.

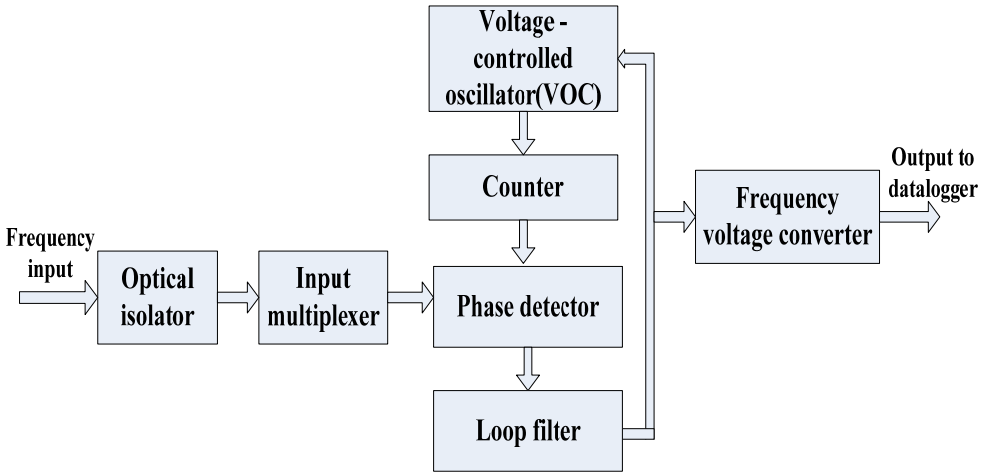


Figure 4.4.1 Working principle of fan rotation speed measurement

The frequency signals from sensors were fed into the optical isolator and transmitted to the multiplexer which selected one signal channel to the phase-locked loop (PPL) circuit. This PPL circuit functioned as a frequency multiplier. Firstly, the voltage-controlled oscillator (VCO) generated a local signal and it was fed into a divide-by-n counter. Then, the output of the counter was compared with the input fan frequency in the phase detector and the difference was filtered. Finally, the output from the loop filter fed back to the VCO and controlled it to track and follow the input fan frequency. As a result, the output signal was proportional to the fan RPM. The frequency-voltage converter circuit was designed to transform the output mode that can be accepted by the data logger. The integrated electronic circuit boards mentioned above as well as

corresponding power supplies were all mounted on an aluminium panel and stored in a cabinet for moisture protection (Figure 4.4.2)

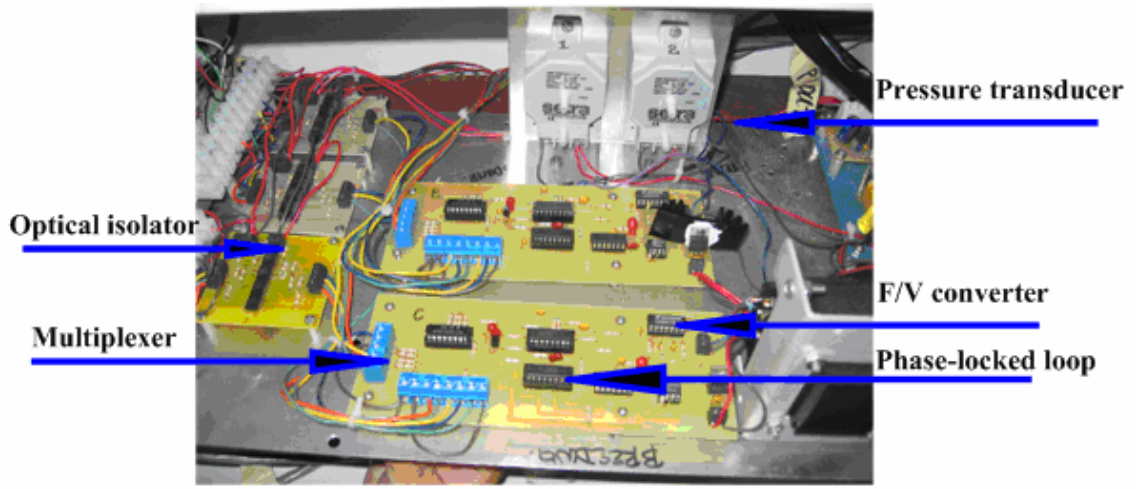


Figure 4.4.2 Fan rotation speed measurement system

4.4.2 Verification of fan flow rate

Fan field performance would be affected by barn environment due to adverse condition as well as power supply instability. Hence, air flow rate derived from fan curve method need to be corrected in order to obtain actual flow rate. All the single and variable speed fans had straight ducts and guards at the exhaust. The verification of the fan flow rate was based on ASHRAE Standards (AMCA Standard Handbook 51). Figure 4.4.3 shows traverse measurement plane where 24 points of air velocity needed to be measured. An anemometer with an accuracy of ±1.5% at 10.16 m s^{-1} (Model 8385, VelociCalc Plus Air Velocity Meter, TSI Inc., MN, USA) was used to measure air velocity.

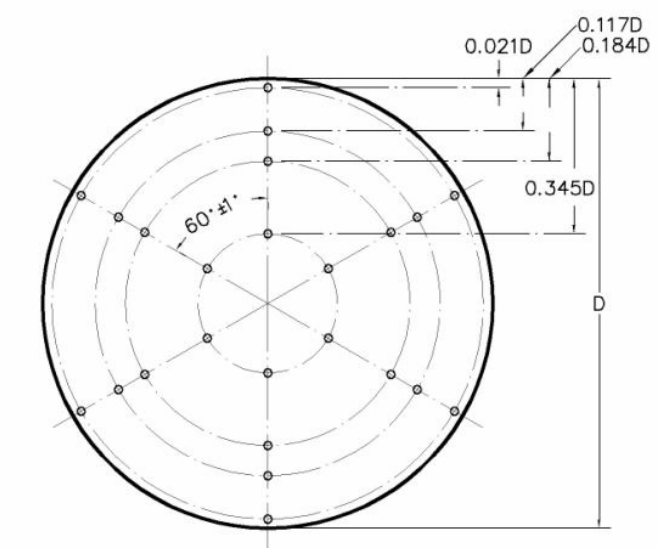


Figure 4.4.3 Measurement points in the traverse plane

The average of the four measurements at traverse plane at 60^{o} was measured to accuracy of 0.2 D (D: diameter of the duct). Under full speed and various static pressure conditions, 24 points of each size of fan were measured. Each point measured three times. A total of four variable speed fans (TR12F, TR16F, TR20F, and TR24F) and a single speed fan (TR36F) were measured in the field. The fan flow rate was the products of average air velocity and corresponding fan transverse plane area. The calibration results were displayed in Appendix B. All the values were within 10% of the manufacture's specifications for the exhaust fans at measured static pressures and speeds. On one hand, the airflow rate deviation was caused by instability of power supply, dust build-up and adverse environment influence. On the other hand, measurement error was attributed to this bias because the unstable outside wind speed and direction would greatly influence the air velocity measurement.

4.5 Dust Measurement

Total dust concentration included all the dust particles that are suspended in the air. The method of total dust concentration complied with the NMAM 0500 (NIOSH, 1994). The Airlite personal sampling pumps (SKC Inc., PA, USA) that were attached to the iron bars were set up in the middle of the room, 1.5 m above the floor (circles shaded with orange in Figure 4.3.1). The constant airflow of the pump was adjusted to 2 L/min (2

litres per minute) and calibrated before each sampling. Tared 37-mm, 5-µm PVC filters (SKC Inc., PA, USA) were loaded into the three-piece cassettes and desiccated prior and after the collection in the experimental rooms for 24 h. The filter filled with dust was weighed on a microbalance (Mettler, AE 163, Mettler Instrument, Zurich, Switzerland) with accuracy of 0.0001 g. For diurnal measurement, the total dust concentration was measured continuously for 8 h from 8:00 am to 4:00 pm during which the staff worked in the barn representing average 8-h total dust concentration. The 8-h measurement was conducted in successive two days. For seasonal measurement, it was collected continuously for 3 h from 9:00 am-12:00 pm twice in the first and third days of the testing days.

Dust deposition reflected the dynamic movement of the particles. There were two dust deposition collection locations in each room (circles shaded with yellow in Figure 4.3.1). Open-face cassettes with 37-µm PVC filter were used to collect the deposited dust and measured using the same method as total dust concentration as mentioned above. A 2-day collection was conducted in diurnal measurement months while 3-day collection for seasonal measurement months.

4.6 Environment Condition Measurement

Inside relative humidity, inside and outside temperature as environmental parameters were measured and recorded. The measurement locations were at the center of the nursery and farrowing room 1.5 meter above the floor (circles shaded with blue in Figure 4.3.1). Gestation room had two inside temperature measurement locations and one outside temperature measurement locations (Figure 4.3.1). Temperature sensors were TC 1047 (accuracy: ± 0.5^{o}C, Microchip Technology Inc., Chandler, AZ, USA) and relative humidity sensors were HIH-4000 (accuracy ± 3.5 % RH, Honeywell Inc., Freeport, Illinois, USA). The TC 1047 sensors were linear voltage output temperature sensors and their output voltage was directly proportional to the measured temperature. It was chosen for its range of -40^{o}C to 125^{o}C and its immunity to voltage drop and voltage noise over long lines, and its long-term stability. HIH-4000 relative humidity sensor is a laser trimmed, thermo set polymer capacitive sensing element with on-chip

integrated signal conditioning. Although they had excellent resistance to application hazards such as wetting and dust, housing made from PVC pipe was constructed for the RH/T sensors to protect them in the swine barns. A rubber was attached to the end of pipe to prevent the noise from light.

4.7 Data Acquisition System

All the environmental parameters or monitoring signals from temperature sensors, relative humidity sensors, pressure transducers, single and variable fan speeds, and NH_3, CO_2 concentrations were acquired by two data loggers (CR10X, Campbell Scientific Corporation, USA) located outside of the rooms, one for nursery and farrowing rooms, and the other for the gestation room. CR 10X data logger is a fully programmable device with 12 single-ended channels or 6 differential channels. It also had 8 digital I/O input to control the peripheral. Figure 4.7.1 showed the schematic data acquisition system. The recorded data can be downloaded by a personal computer through 9 pin serial ports communication mode.

Data acquisition programs were compiled using CR10X programming software. The execution intervals of the two loggers were set 10 seconds and 40 seconds respectively because of different signal inputs. Averaged values for every hour were used for evaluation. The complete programming of two data loggers was illustrated in the Appendix D.

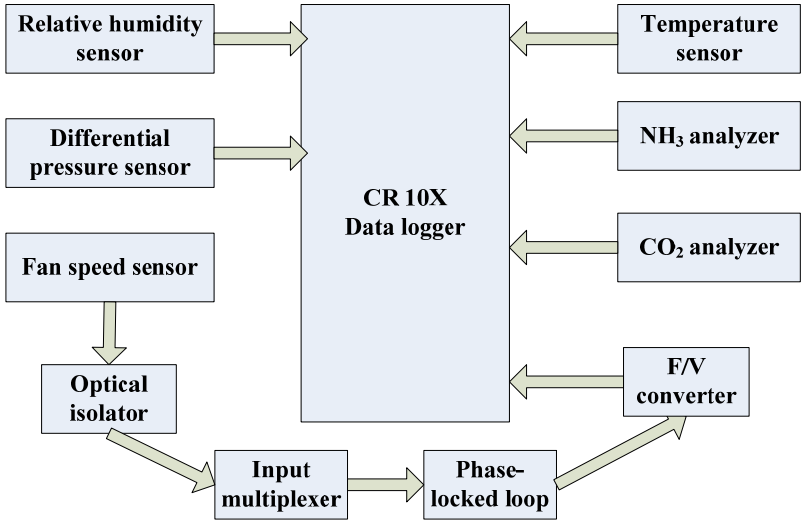


Figure 4.7.1 Configuration of data acquisition system

4.8 Animal Management

Room cleanliness is an important factor for odour emissions as the room is dirtier, the higher the odour emissions (Miller, 2004). Subjective assessment of building cleanliness was conducted for this study. During each measurement day, the cleanliness was recorded twice at 9:00 am and 3:00 pm for diurnal measurement day or 9:00 am once for seasonal measurement day. A 1-5 scale visual estimation was adopted to quantify the cleanliness condition of the rooms as exhibited in Table 4.8.1

Table 4.8.1 Five scales for room cleanliness

Scale	Indication	Description
1	very clean	No manure/urine on the floor
2	clean	10-20% manure/urine on the floor
3	medium	20-50% manure/urine on the floor
4	dirty	More than 50% manure/urine on the floor
5	very dirty	All covered with manure

Pig weight is a very important factor for odour and gas production. Total farrowing and gestation pig weights were calculated by multiplying total number of pigs by average pig weight which was weighed or estimated by experienced workers. For mean nursery weight, two pens of pigs were chosen to weigh on a scale located in the hallway after each testing. Total weight was derived from total number multiplied by mean weight. At the same time, total animal unit (AU) was obtained by dividing the total anima weight by 500 kg animal mass (1 animal unit = 500 kg animal mass).

Worker and animal activities might be one of the reasons to explain the odour, gas and dust concentration fluctuation. Therefore, the times of feeding, cleaning, checking and medical treatment were recorded during each testing period when researchers were on the spot.

4.9 Calibration of the Sensors

Prior to installation, all temperature sensors, relative humidity sensors, pressure transducers, fan hall sensors, dust pumps were calibrated in the Electronics Laboratory, Department of Agricultural and Bioresources Engineering, University of Saskatchewan. Climatic control chamber (B-M-A ,Inc. AYER, MA, USA), humidity generator (1200 humidity generator, Thunder Scientific Corporation, NM, USA), precision pressure

indicator/calibrator Druck DPI 605 (GE Industrial Sensing, Fairfield, CT) and manometer (34FB2TM, Meriam Instrument, Div of the Scott & Fetzer Co. Cleveland, Ohio, 44102, USA), 50 MHZ pulse generator (Model 801, Wavetek, CA, USA) ,1.3 GHZ Frequency Counter (FC130A, Beckman Industrial Co., CA, USA), and pocket flow calibrator (Series 580, Kurz Instrument Inc, Monterey, CA) were used to calibrate these sensors. The calibration procedure and results are presented in Appendix A.

4.10 Statistical Modeling

Statistical models were developed to predict the odour and gas concentrations and emissions as a function of ambient temperature, indoor temperature, ventilation rate, pig density, etc. For indoor air quality model, three principle energy inputs should be considered: 1) the energy input from animals; 2) the energy input from inside and outside environment; 3) the energy input from the ventilation system (Berckman et al., 1994). Considering the input variable should be measurable and quantifiable, the animal unit can be used to reflect the energy input from animal; ambient temperature, room temperature were treated as energy input from outside and inside environment. Furthermore, the ventilation rate stood for the input from the ventilation system. Therefore, in the model development, the odour and gas concentrations and emissions were treated as dependent variables, and the four factors-animal unit, ventilation rate, ambient temperature, and room temperature were deemed as independent variables.

SPSS (2005) multiple linear regression was used to simulate the relationship between dependent variable and independent variables. The least squares method is the theoretical foundation of the linear regression which minimizes the sum of residuals (the difference between predicted and measured values) squares. In the process of modeling, 70% of the data collected were used to establish the predictions models, while the rest of 30% of data were utilized to validate the developed models. Pearson's coefficient of regression R square was used to check the model validity. The closer the value to 1, the better the regression is. The coefficient gives what fraction of the observed behaviour can be explained by the given variables. Paired t test was also utilized to validate the

predicted value and measured value. Paired t test is to test the null hypothesis that the means of two normality distribution population are equal. If the significance of t test larger than 0.05 ($p>0.05$), it means the predicted and measured data have no significant difference. Then, we can consider the statistical model is acceptable, the higher significance level, the better the model is, vice versa. According to "Standard Guide for Statistical Evaluation of Indoor Air Quality Models" (ASTM, 2003), fractional bias (FB) could be adopted as model evaluation method. The suggested evaluation limit is $-0.25 < FB < 0.25$. The closer FB to 0, the better the regression model is.

$$FB = \frac{2 \times (C_p - Co)}{(C_p + Co)} \tag{4.2}$$

where

C_p is the mean predicted;

Co is the mean measured.

5 RESULTS AND DISCUSSION

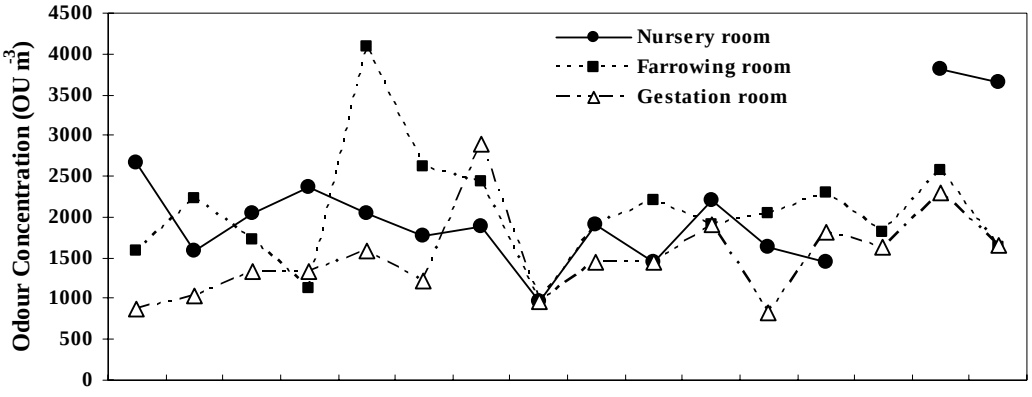
5.1 Diurnal Odour and Gas Concentration and Emission Profiles

Diurnal odour and gas concentration and emission rate profiles reveal the concentrations and emission rates variation under different climatic conditions. Three diurnal measurements were conducted in the nursery, farrowing and gestation rooms in August, 2006, February and April 2007, respectively. During each measurement, odour, NH_3, CO_2, H_2S, CH_4, and N_2O samples were taken every 3 hours for 2 days, in addition, hourly NH_3, CO_2, and H_2S concentrations were also measured for 2 days. However, a portion of CO_2 and H_2S concentration data were missing due to device measurement range limitation and malfunction. Two factor strip-block experiment designs were used to investigate the influence of room type, temperature, ventilation rate, animal unit (pig number and weight) and animal management on odour and gas concentrations and emission rates.

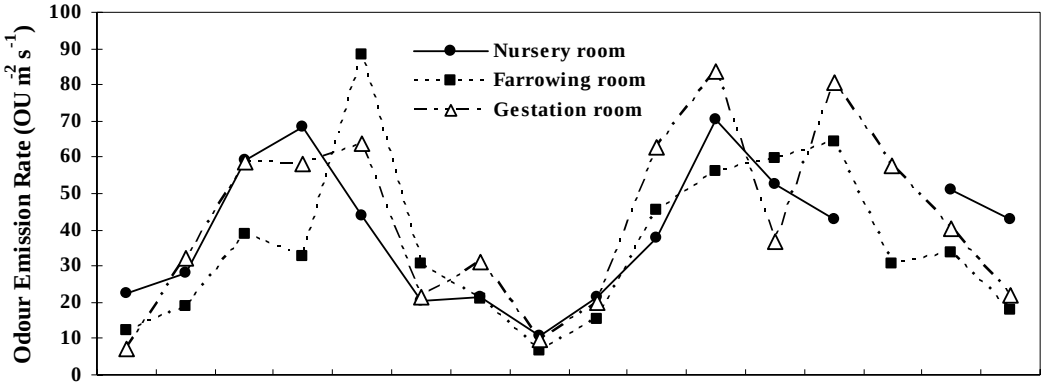
5.1.1 Diurnal odour and gas concentration and emission profiles in August

The diurnal measurement in warm climate was conducted from 06:00 am August 21st to 06:00 am August 23rd, 2006.

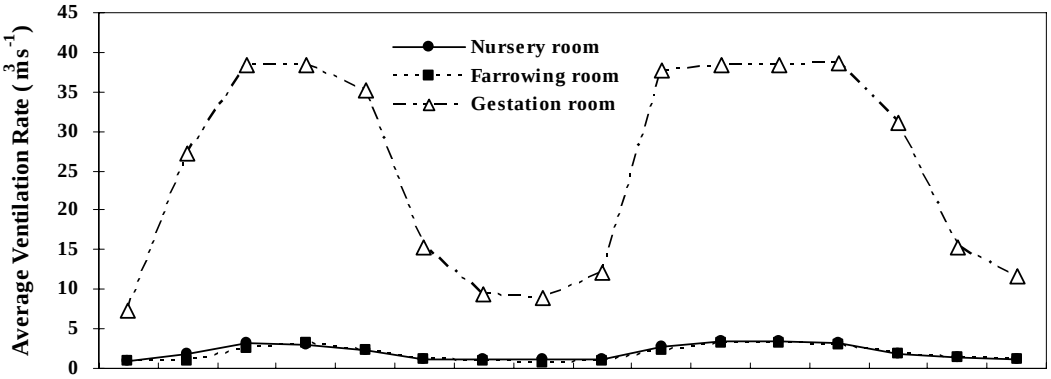
5.1.1.1 Odour concentration and emission profiles



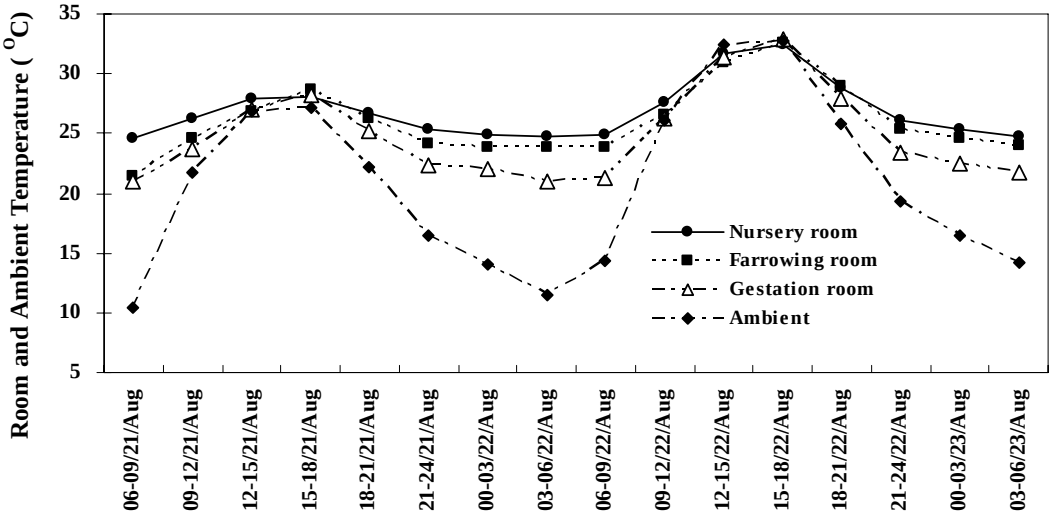
(a) Odour concentrations



(b) Odour emission rates



(c) Average ventilation rates



(d) Room and ambient temperatures

Figure 5.1.1 Diurnal variation of odour concentrations and emissions in August

Figure 5.1.1 summarizes the diurnal variation of odour concentrations, emission rates, ventilation rates and inside and outside temperature in nursery, farrowing and gestation rooms. Table 5.1.1 also gives the statistical descriptions of mean 3-h odour concentration, odour emission, ventilation rate, and room temperature of nursery, farrowing and gestation rooms as well as their animal inventory.

The geometric means of 3-h odour concentration for the two days from the nursery, farrowing, gestation rooms were 1979, 1963, 1434 OU m^{-3}, respectively. One datum was missing in the nursery room due to a leaking bag. Measured odour concentration varied from 955 to 3822, 955 to 4096, and 883 to 2896 OU m^{-3} for the nursery, farrowing, and gestation rooms, respectively. The statistical analysis results indicated that there were no significant difference of odour concentration among the three rooms in August (P=0.08>0.05). From the Figure 5.1.1, it is easy to find out that odour concentration peaks differed in room type and time. Take the farrowing room for example, the peak of the first day occurred at 18:00-21:00 h period, while the second day occurred during 00:00-03:00 h period. The reason was not clear. One possible reason might be related to the ventilation rate. Although the peak concentration periods were different, they all occurred at night when ventilation reduced to low level. The amount of odour within the building was accumulated leading to the increase of odour concentration. The maximum of odour concentrations were almost 3-4 times of minimum level for all three rooms. The “diurnal” factor had no significant effect on odour concentration, which meant no specific variation pattern of odour concentration was observed in all three rooms (P>0.05). Although no apparent variation pattern exhibited, large standard deviation reflected large odour concentration fluctuation.

Diurnal variations of ventilation rate were observed in the two consecutive days, being high within 12:00-18:00 h periods and low during 00:00-09:00 h periods. This variation pattern of ventilation rate was similar to the room temperature fluctuation since inside temperature was closely related to ambient temperature and ventilation rate under hot climate. The ventilation rate of the gestation room was much larger than the nursery and farrowing rooms due to its large size and animal number.

Odour emission rates were expressed in units of odour unit per square meter of floor area per second. From statistical analysis, it was found that there were no significant difference among odour emission rates of the three rooms with geometric means of 34.9, 29.9, and 35.1 OU m^{-2} s^{-1} for the nursery, farrowing, and gestation rooms, respectively ($P>0.05$). If the odour emission was expressed based on the animal unit, the corresponding odour emission were 434.6, 484.0, and 236.9 OU AU^{-1} s^{-1}. Significant diurnal variations of odour emission rate was presented in Figure 5.1.1 ($P<0.05$), which followed the same trend as the variation of the ventilation rate. High odour emission rate occurred in the daytime while low at the night. Since odour concentration alone could not determine the emission rate, ventilation rate played an important role. Large variation of ventilation rate contributed to the obvious variation of the emission rate. As mentioned before, no pronounced variation pattern of odour concentration was observed, so the variation pattern of odour emission rate was determined mainly by ventilation rate pattern. Additionally, when the ventilation rate stayed stable during the daytime, the variation of odour emission rate was largely dependent on the variation of odour concentration. The peak occurred during the period of 18:00-21:00 h both for the farrowing and gestation rooms in the two days. The reason was the relatively high ventilation rate and odour concentration during this time period. The ratio of maximum to minimum emission could reach to 7, 13, and 11 respectively for the nursery, farrowing and gestation rooms. No interaction effect between diurnal factor and room type factor on odour concentration and emissions made it possible to combine odour concentration and emission data from the three rooms together to compare the means.

Table 5.1.1 Descriptive statistics on odour concentrations and emissions in August

	Nursery			Farrowing			Gestation		
Variable	**Mean(S.D)**	**Max**	**Min**	**Mean(S.D)**	**Max**	**Min**	**Mean(S.D)**	**Max**	**Min**
Odour concentration (OU m^{-3})	1971(768)	3822	955	1963(703)	4096	955	1434(531)	2896	832
Odour emission (OU m^{-2} s^{-1})	34.9(20.5)	70	11	29.4(21.1)	88	6.9	35.1(24.6)	83.8	7.4
Odour emission(OU AU^{-1} s^{-1})	434.6(237.6)	873	131	484(379.2)	1449	113	236.9(171.4)	566	50
Ventilation rate (m^3 s^{-1})	2.09(0.93)	3.45	0.9	1.83(0.93)	3.15	0.8	25.2(13.1)	38.6	7.32
Room temperature (^oC)	26.9(2.4)	32.4	25	26.0(2.9)	32.6	21	24.9(3.7)	32.9	21
Rom relative humidity (%)	55(13.5)	73.6	26	51(12.4)	67.5	23	55(17)	79.7	20.7
Pig inventory	213			13			301		
Average pig mass (kg)	20.2			215			250		
Total pig mass (kg)	4302.6			2795			75250		

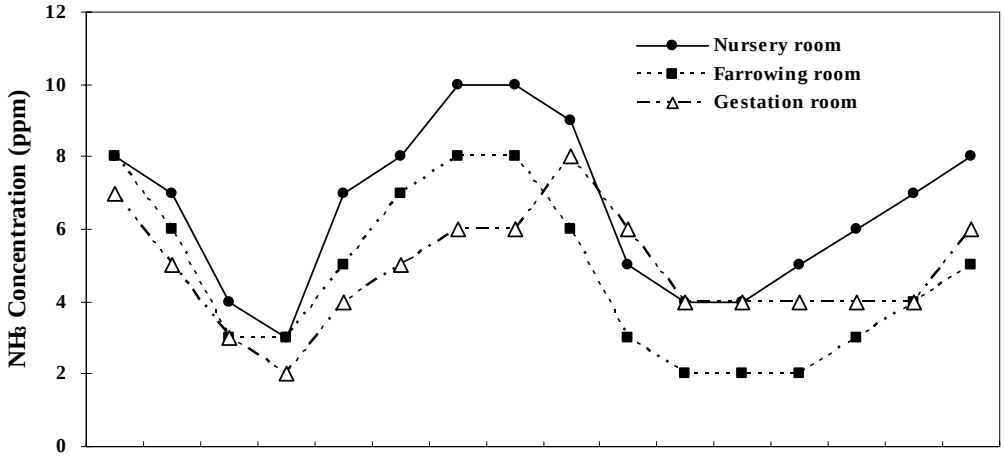
* Means of odour concentration and emission were geometric means.

The mean ambient temperature(^oC) : 20.7(S.D. 7.2), Max: 32.7, Min:10.4

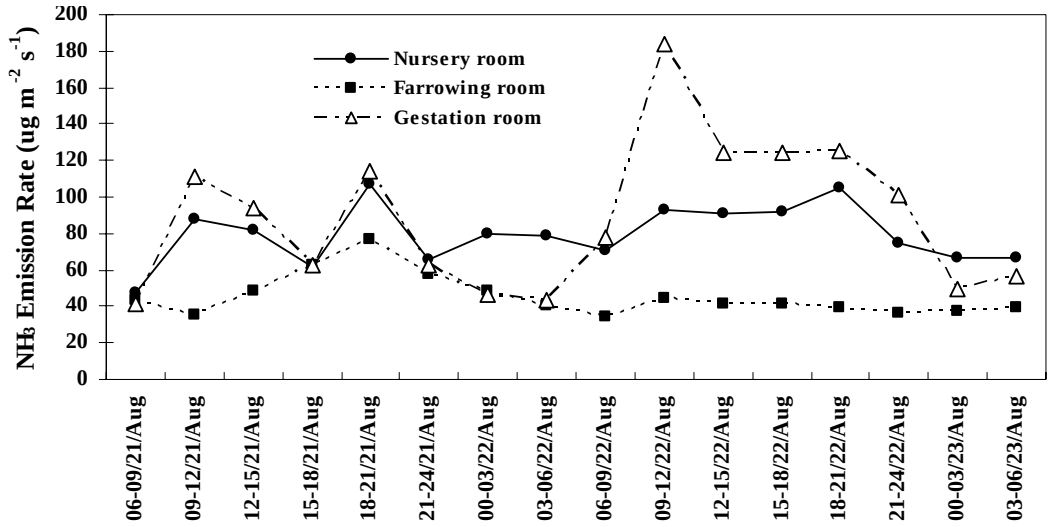
No.of mean= 15 for nursery, n=16 for farrowing, gestation

Statistical analysis also revealed that "day" factor had significant effect on odour emission rate for all three rooms (P<0.05). This is because the mean ambient temperature of the second day was higher than the first day. As a result, the ventilation rate was increased and odour emission increased. Since diurnal variations of odour emissions existed and different days had statistically significant effect on odour emission in summer, it indicated that using randomly measured emission rates would cause great uncertainty for source emission data.

5.1.1.2 Gas concentration and emission profiles in August

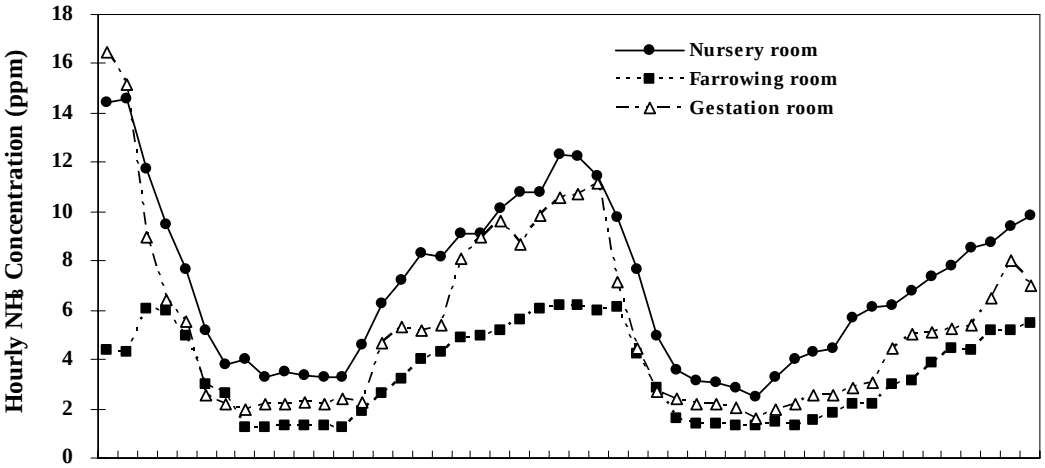


(a) 3-h NH_3 concentrations

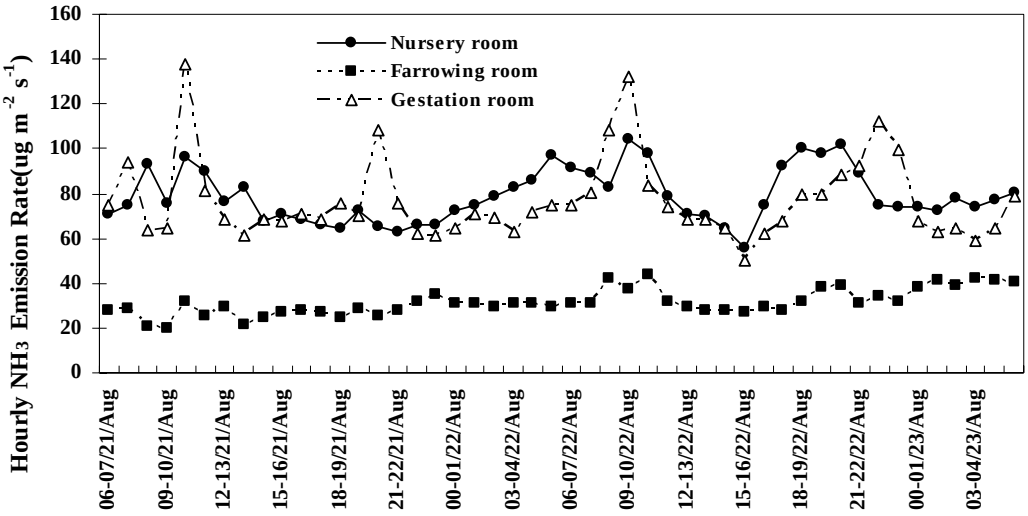


(b) 3-h NH_3 emission rates

Figure 5.1.2 Average 3-h NH_3 concentration and emission rates in August



(a) Hourly NH_3 concentrations



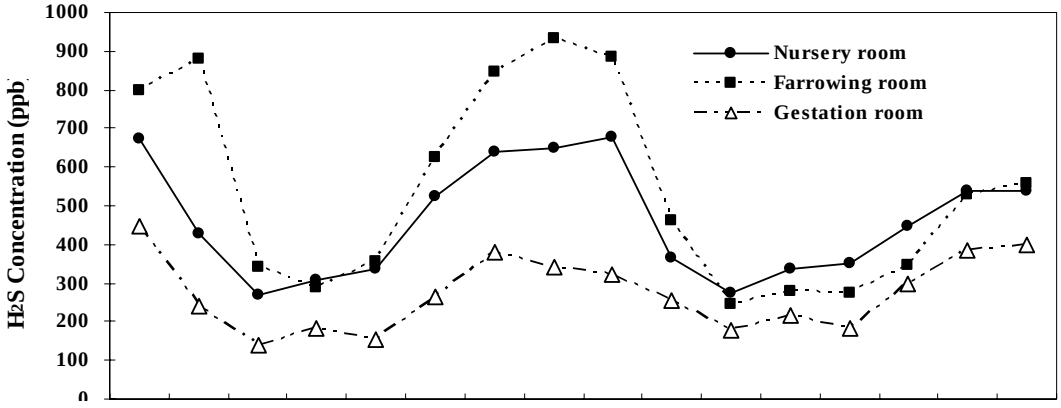
(b) Hourly NH_3 emission rates

Figure 5.1.3 Hourly NH_3 concentration and emission rates in August

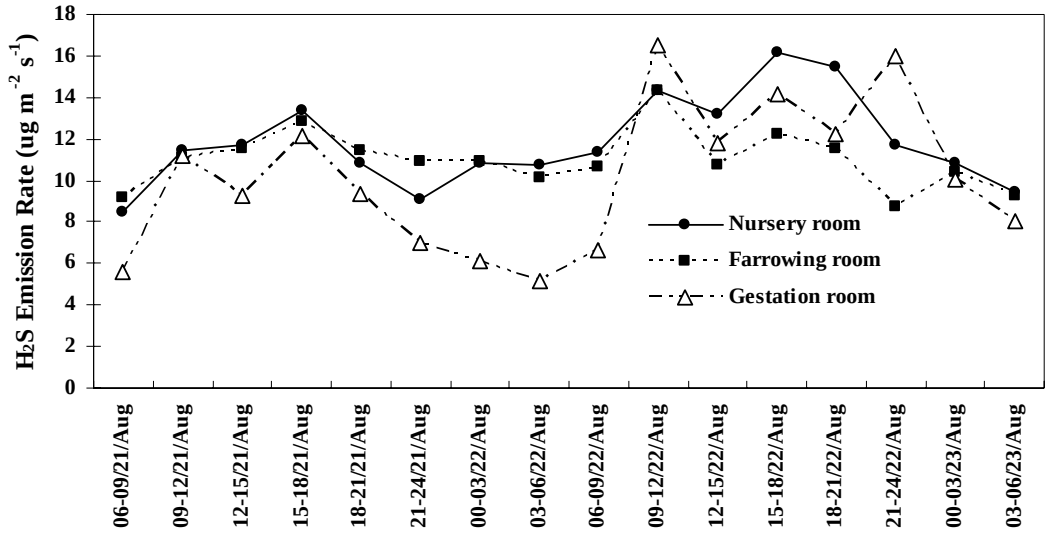
Figures 5.1.2 and 5.1.3 present average 3-h NH_3 concentration from gas sampling bags, while hourly NH_3 concentrations were sampled at 15 min interval for each room and averaged 4 data as hourly concentration. Hourly NH_3 concentration and emission profiles (Figure 5.1.3) provided more detailed variations within each room. When comparing the results between average 3-h concentrations and hourly concentrations, we find that hourly concentrations were more or less higher or lower than the values of average 3-h concentration. This might be caused by different sampling methods. The air mixed completely in the 3-h continuous sampling procedure while the hourly concentration sampling procedure only drew the air in a short period of time representing true gas concentration at the short 1 min sampling period when the data were recorded. Hence, it is essential to emphasize the sampling period when referring to the concentration.

A significant variation trend was presented in the Figure 5.1.2 and was also confirmed by the statistical analysis that the diurnal factor had significant effect on NH_3 concentration (P<0.05). The lowest level approached between 15:00-18:00 h for all three rooms in two days and the peak levels occurred during 03:00-06:00 h. This concentration pattern was the opposite of the ventilation rate fluctuation pattern. The

high ventilation rate due to the high outside temperature caused lower ammonia concentration in the rooms. These results were also found in the other studies (Groot Koerkamp, 1998; Sun, 2005). NH_3 concentrations in the nursery room varied in the range of 3 to 10 ppm, while the farrowing and gestation rooms varied from 2 to 8 ppm. As shown in Figure 5.1.2, diurnal patterns in NH_3 emissions showed less variation than the concentration although "diurnal" factor still had significant effect on NH_3 emissions (P<0.05). The less variation of NH_3 emissions is because the emission was derived from multiplying the ventilation rate and exhaust concentration, while they had an inverse relationship. The mean of NH_3 emission from the nursery, farrowing, and gestation rooms were 79.3, 45.5 and 88.7 μg m^{-2} s^{-1}, respectively. There was no significant difference of NH_3 emissions between the nursery and gestation rooms (P>0.05), but they were significantly higher than the farrowing room (P<0.05). From hourly emissions, it was notable that there were four sharp peaks in two days, two within the period of 09:00-11:00 h, while the other two during 20:00-23:00 h, which might be related to increased animal activities.



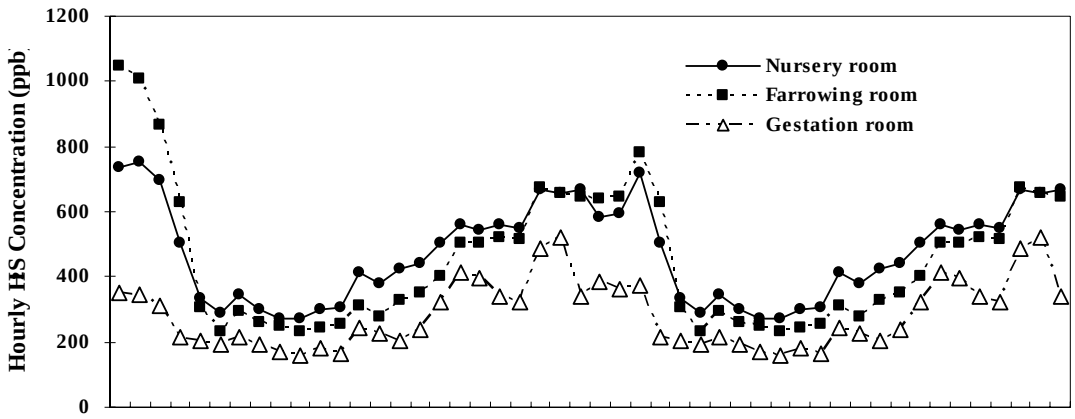
(a) 3-h H_2S concentrations



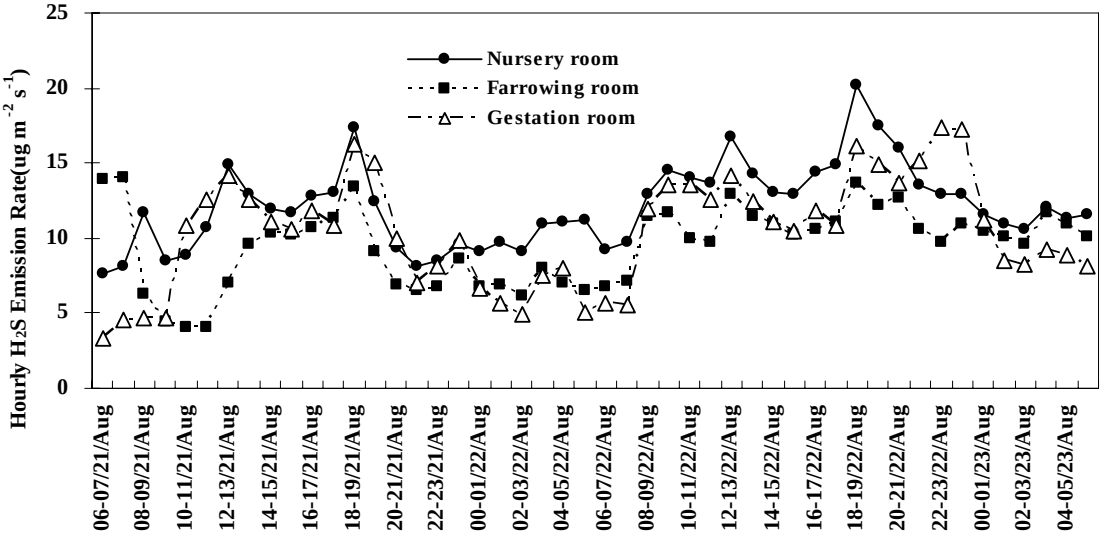
(b) 3-h H_2S emission rates

Figure 5.1.4 Average 3-h H_2S concentrations and emissions in August

Figures 5.1.4 and 5.1.5 give the H_2S concentration and emission profiles under hot weather conditions. Hourly concentrations and emissions provided more concrete variation configuration than average 3-h concentrations and emissions. There were also some differences in concentrations and emissions between hourly and average 3-h profiles. H_2S concentration in farrowing room was higher than that of the nursery room for most of the time in the average 3-h concentration figure, while both rooms had fairly similar concentrations in the hourly figure. The main reason was the different sampling methods as discussed for the NH_3 concentration. The general diurnal variation patterns were similar in all three rooms, i.e., significant diurnal variations of H_2S concentration were observed, high level in the mid night and low level in the late afternoon. The change of ambient temperature and ventilation rate were the causes for this phenomenon.



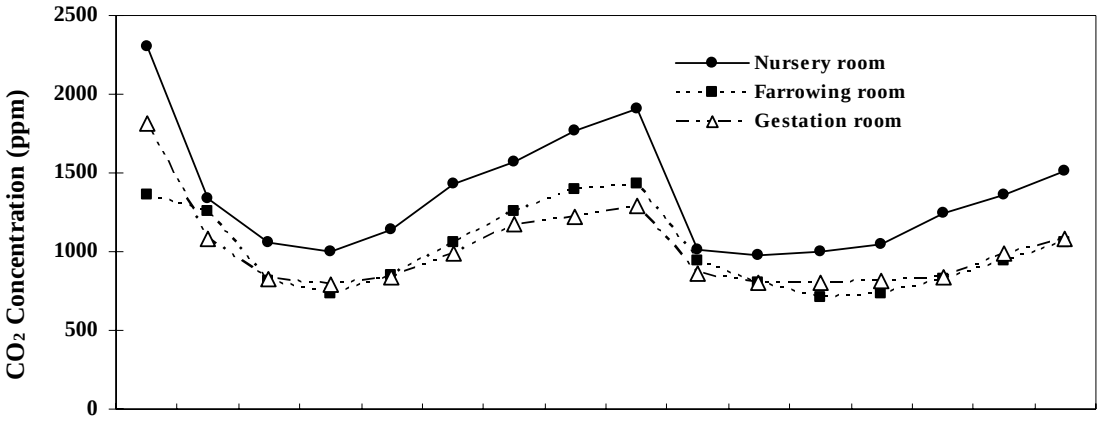
(a) Hourly H_2S concentrations



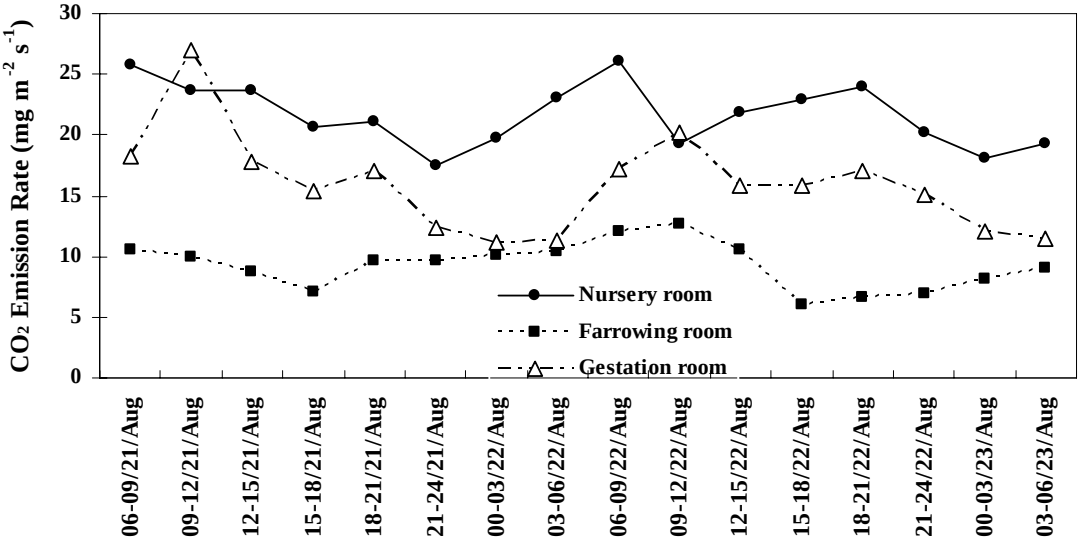
(b) Hourly H_2S emission rates

Figure 5.1.5 Hourly H_2S concentrations and emissions in August

Mean H_2S concentration of farrowing room was higher than nursery room and gestation room with means of 541, 460, and 274 ppb, respectively. Although significant effect of "diurnal" factor was detected by statistical analysis, the fluctuation pattern was not so apparent just like the ammonia emission variation. The mean emissions released from nursery, farrowing and gestation room were 11.8, 11.0 and 10.1 μg m^{-2} s^{-1}, respectively.

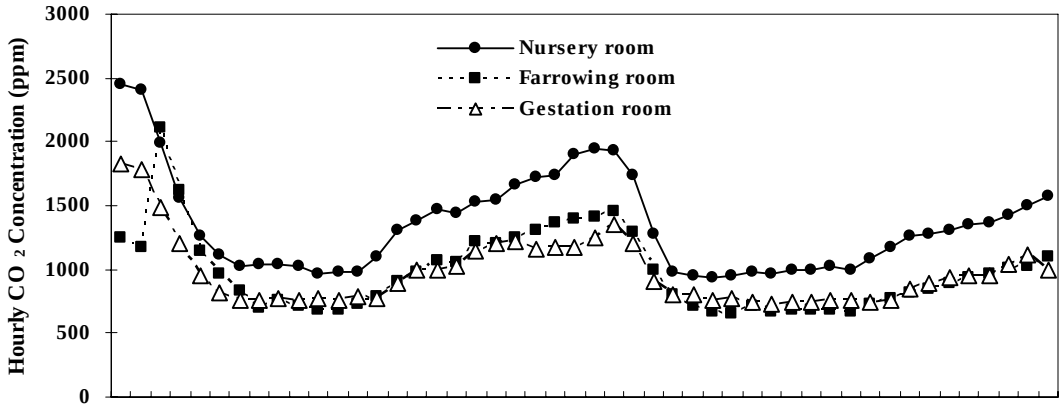


(a) 3-h CO_2 concentrations

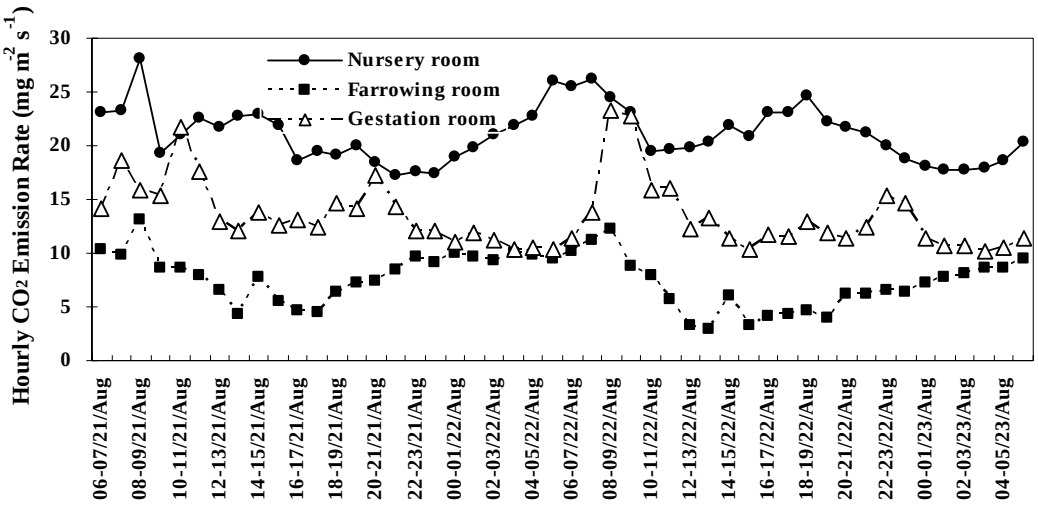


(a) 3-h CO_2 emission rates

Figure 5.1.6 Average 3-h CO_2 concentrations and emissions in August



(a) Hourly CO_2 concentrations



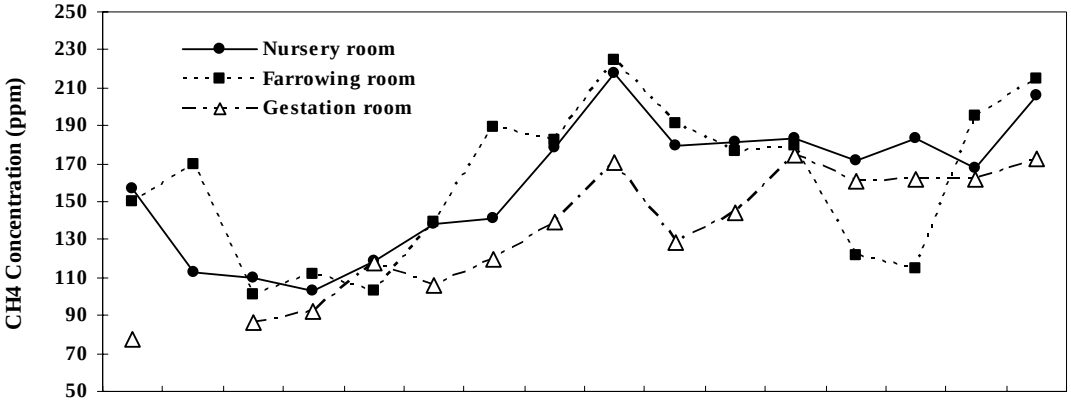
(b) Hourly CO_2 emission rates

Figure 5.1.7 Hourly CO_2 concentrations and emissions in August

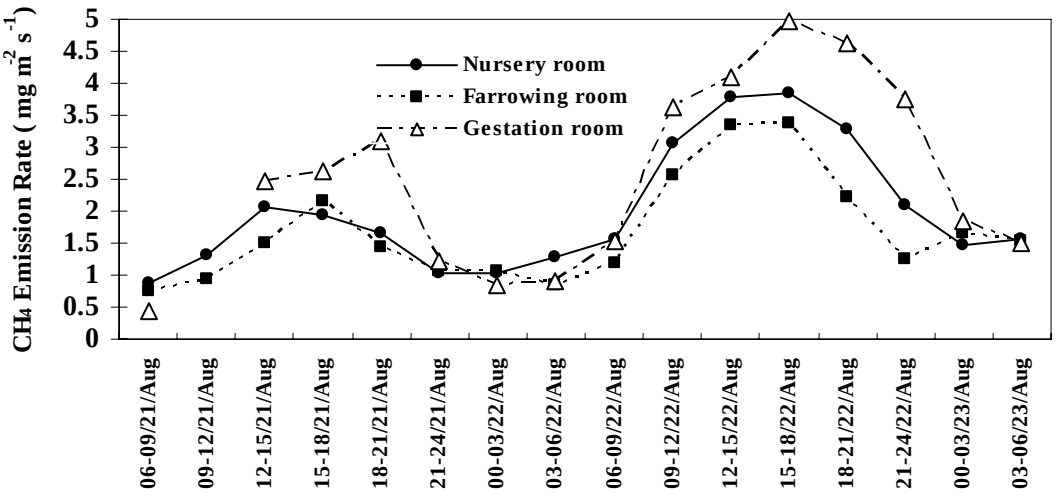
The diurnal variation of CO_2 concentrations and emissions are shown in Figures 5.1.6 and 5.1.7. The hourly profiles were almost the same as the average 3-h profiles, which was different from NH_3 and H_2S profiles. It was difficult to explain why the difference occurred in NH_3 and H_2S but not in CO_2. The graph presented apparent diurnal pattern and also was confirmed by the statistical analysis giving in Appendix C (P<0.05). The peak concentrations for the nursery, farrowing and gestation rooms were 2300, 1430, and 1810 ppm, respectively, occurring during 06:00-09:00 h for all three rooms when the ventilation rate dropped to its lowest level. Nevertheless, the lowest concentrations happened during 15:00-18:00 h for the first day and 09:00-12:00 h for the second day for all three rooms when ventilation rate increased to its high running conditions. The statistical results revealed that CO_2 emissions differed significantly between the three rooms with mean emission of 269.8, 216.7 and 107.6 mg m^{-2} s^{-1} for the nursery, farrowing and gestation rooms, respectively (P<0.05). The analysis also revealed that "diurnal" effect had statistically significant effect on CO_2 emissions (P<0.05).

Methane (CH_4) was an important greenhouse gas and it was necessary to characterize the CH_4 concentration and emissions from swine barns. One datum from the gestation room was missing because of improper handling of the sample tubes. According to

Figure 5.1.8 and statistical result given in table 5.1.2, no significant difference of CH_4 concentrations and emissions among three rooms was found (P>0.05). No diurnal variation patterns of CH_4 concentrations were observed, however, significant diurnal variation of CH_4 emissions existed (P<0.05). The emission peaked at the period of 12:00-21:00 h for all three rooms in successive two days. This mainly was attributed to diurnal variation of ventilation rate associated with the ambient temperature. Mean CH_4 concentrations were 159.4, 103.2 and 101.3 ppm for the nursery, farrowing and gestation rooms, respectively, and mean CH_4 emissions of 2.0, 1.7 and 2.5 mg m^{-2} s^{-1}, respectively.



(a) 3-h CH_4 concentrations



(b) 3-h CH_4 emission rates

Figure 5.1.8 Average 3-h CH_4 concentrations and emissions in August

N_2O concentrations were also measured during the testing days. The N_2O concentrations varied within a small range with 0.02 standard deviations for all three rooms. The concentrations of exhaust air were very low and mean concentrations were only 0.39, 0.41 and 0.39 ppm, respectively. These values were not much higher than the N_2O concentration in the ambient air with average concentration of 0.29 ppm. Consistent low concentration of N_2O indicated that N_2O from pig barns contributed little to the greenhouse gas emissions.

Table 5.1.2 Descriptive statistics on gas concentrations and emissions in August

Variables	Nursery			Farrowing			Gestation		
	Mean(S.D)	Max	Min	Mean(S.D)	Max	Min	Mean(S.D)	Max	Min
NH_3 concentration (ppm)	6.6(2.2)	10	3	4.7(2.2)	8	2	4.9(1.5)	8	2
NH_3 emission(ug m^{-2} s^{-1})	79.3(16.1)	107	48	45.5(11.4)	76	34	88.7(40.4)	184	42
NH_3 emission (ug AU^{-1} s^{-1})	978.1(200.5)	1329	594	748.7(186.9)	1256	564	598.9(272.8)	1242	281
H_2S concentration (ppb)	460.3(147.5)	680	270	540.6(253.6)	935	245	274.3(95.8)	445	140
H_2S emission (ug m^{-2} s^{-1})	11.8(2.2)	16	9	11.0(1.4)	14	9	10.1(3.6)	17	5
H_2S emission (ug AU^{-1} s^{-1})	147.1(27.2)	202	106	181.0(23.0)	236	144	68.1(24.2)	112	35
CO_2 concentration (ppm)	1354(383)	2300	980	1011(254)	1430	715	1012(270)	1810	795
CO_2 emission (mg m^{-2} s^{-1})	21.7(2.6)	26	17	9.3(1.9)	13	6	15.9(4.0)	27	11
CO_2 emission (mg AU^{-1} s^{-1})	269.8(32.5)	325	217	152.4(31.3)	209	99	107.6(27.3)	182	75
CH_4 concentration (ppm)	159.4(35.0)	217	103	160.1(40.5)	225	101	134.2(33.1)	174	78
CH_4 emission (mg m^{-2} s^{-1})	2.0(1.0)	3.80	0.90	1.7(0.8)	3.40	0.70	2.5(1.5)	5.00	0.40
CH4 emission (mg AU^{-1} s^{-1})	24.7(12.1)	48	11	27.6(13.7)	56	12	16.9(9.9)	34	3
N_2Oconcentration (ppm)	0.39(0.02)	0.42	0.34	0.41(0.02)	0.44	0.37	0.39(0.02)	0.42	0.32

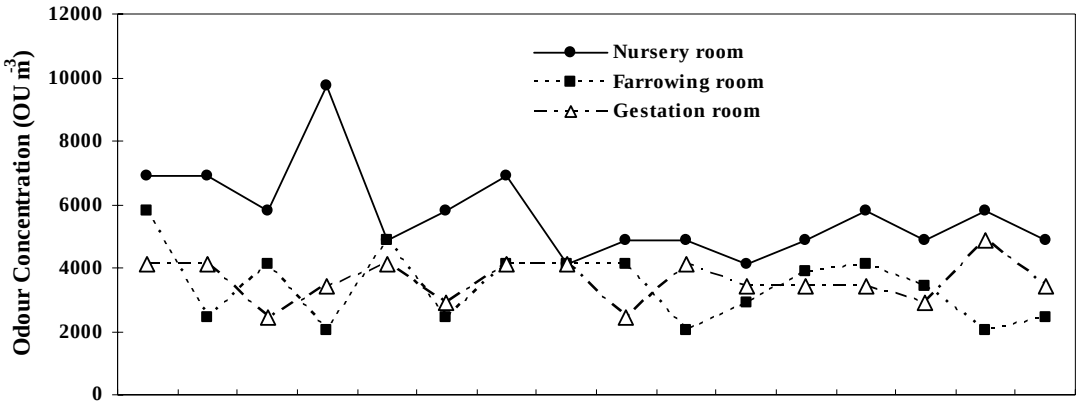
The number of data n=15 for nursery, n=16 for farrowing and gestation

5.1.2 Diurnal odour and gas concentration and emission profiles in February

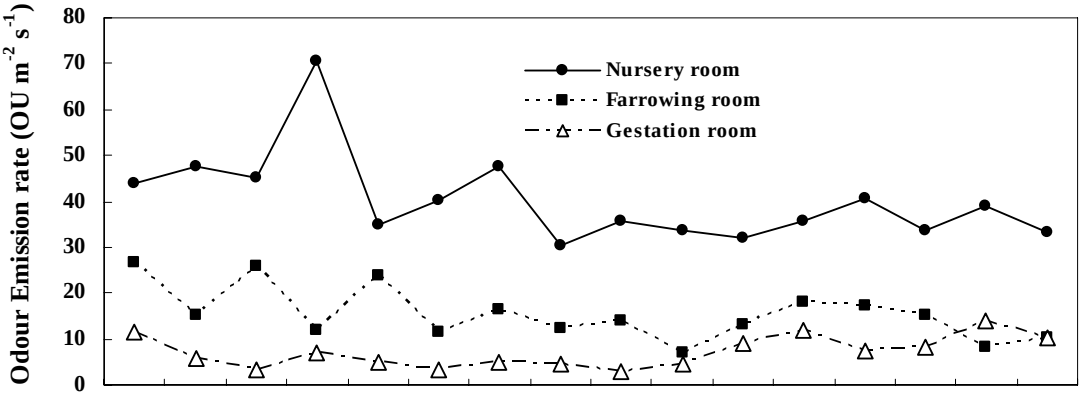
February diurnal measurement was taken from 06:00 am, the 20th day of February, to 06:00 am, the 22nd of February, 2007.

5.1.2.1 Odour concentration and emission profiles in February

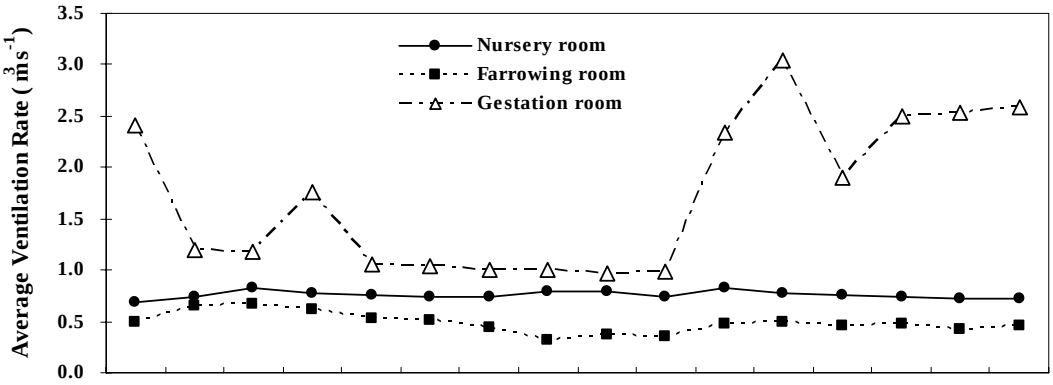
The diurnal variations of odour concentration, odour emission, ventilation rate and ambient temperature in February are illustrated in the following Figure 5.1.9. Meanwhile, statistical analysis from SPSS output for each room is provided in the Table 5.1.3.



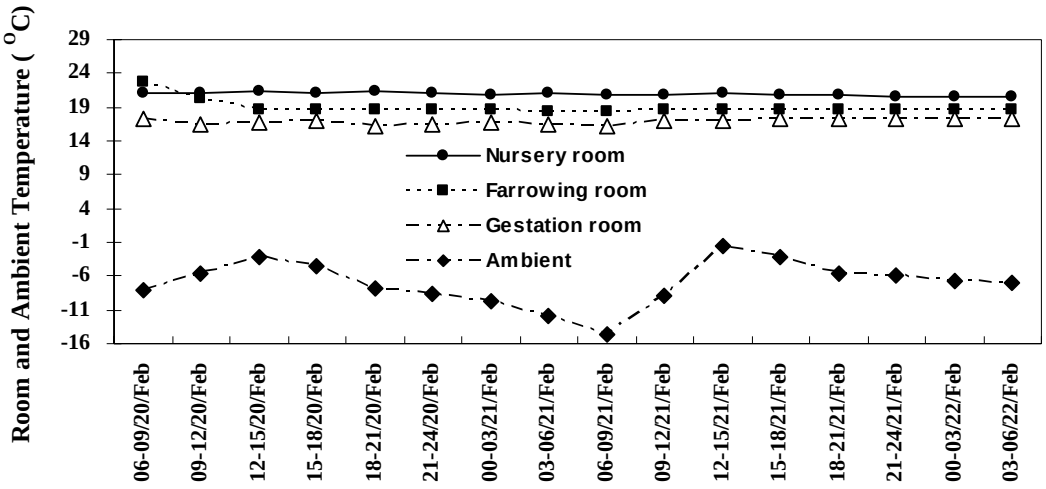
(a) Odour concentrations



(b) Odour emission rates



(c) Average 3-h ventilation rates



(d) Room and ambient temperatures

Figure 5.1.9 Average 3-h odour concentrations and emissions in February

As the graph shown, odour concentrations and emissions fluctuated in a very narrow range for each room. The statistical analysis results also indicated that the "diurnal" factor had no significant effect on the odour concentration and odour emissions for all the rooms (P>0.05). The geometric mean of 3-h average odour for the nursery, farrowing and gestation were 5547, 3252, and 3519 OU m^{-3}, and the mean emissions were 39.3, 30.4, and 6.3 OU m^{-2} s^{-1}, respectively. The odour emissions on animal unit basis were 259.4, 219.1, and 34.6 OU AU^{-1} s^{-1} for the nursery, farrowing and gestation rooms, respectively. The mean ambient temperature of the sampling days was -7.1°C, varying from -14.6°C to -1.6°C. The room temperatures were kept stable. The fluctuation of ventilation rates in nursery and farrowing were so small that the standard deviations were only 0.04 and 0.1 m^3 s^{-1}, respectively. In the nursery and farrowing rooms, only stage 1 fans were in operation, while only 2 stages remained working in the gestation room. The other fans in these three rooms were covered to minimize air infiltration. The minimum ventilation was maintained in order to maintain acceptable air quality. The ventilation rate in the gestation room varied because the stage 2 fans kicked in once in a while. The peak occurrences of odour concentration appeared during the period of 15:00-18:00 h or 18:00-21:00 h when there were worker's feeding and checking activities prior and during the sampling times. The ratio of maximum to minimum concentration was only 2 for all three rooms, lower than that in August. It was also found that the variation trend of odour emissions in the nursery and farrowing

rooms matched well with corresponding odour concentration. It could be explained by the stable ventilation rate. Obviously, the pattern of odour emission rate depended largely on the odour concentration under the condition of stable ventilation rate in cold season. The statistical results revealed that room type had no statistical effect on odour concentrations among three rooms (P>0.05). However, for the odour emissions, significant difference among the rooms occurred (P<0.05). Odour emission from the nursery was the highest, followed by the farrowing and gestation rooms. Furthermore, there was interaction effect between room type and day on odour emissions and no interaction effect on odour concentration and emission between factors diurnal and room type. As for the stable odour emissions, it is reasonable to use randomly measured odour emission rates in cold weather to represent typical emissions from the rooms.

Table 5.1.3 Descriptive statistics on odour concentrations and emissions in February

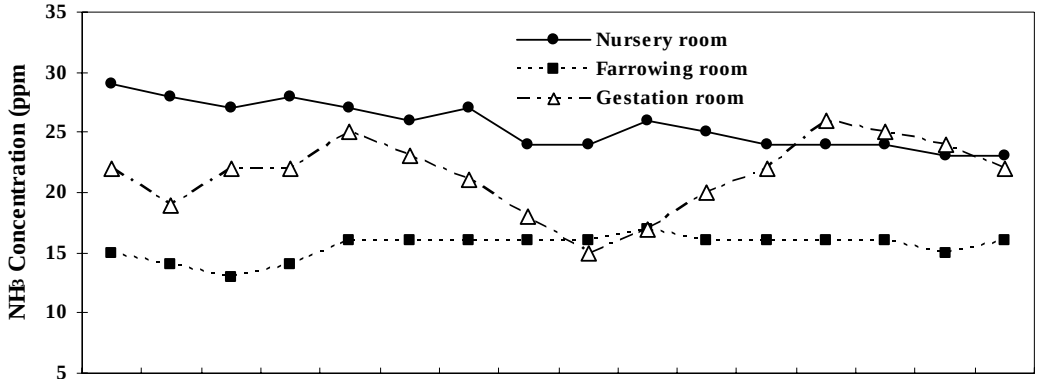
	Nursery			Farrowing			Gestation		
Variable	**Mean(S.D)**	**Max**	**Min**	**Mean(S.D)**	**Max**	**Min**	**Mean(S.D)**	**Max**	**Min**
Odour concentration (OU m^{-3})	5547(1373)	9742	4096	3252(1106)	5793	2048	3519(660)	4871	2435
Odour emission (OU m^{-2} s^{-1})	39.3(9.5)	70.4	30.4	14.3(5.8)	26.5	6.8	6.3(1)	14.1	2.7
Odour emission(OU AU^{-1} s^{-1})	259.4(64.7)	464.8	201	219.1(90.8)	405	104	34.6(19.3)	77	14.8
Ventilation rate (m^3 s^{-1})	0.75(0.04)	0.83	0.68	0.48(0.10)	0.67	0.32	1.72(0.74)	3.04	0.97
Room temperature (^oC)	20.9(0.3)	21.3	20.4	19.0(1.1)	22.7	18.3	16.9(0.4)	17.3	16.3
Rom relative humidity (%)	83.5(9.1)	94.1	66.7	63.6(5.8)	70.3	46.3	73(10.3)	88.4	56.2
Pig inventory	252			14			372		
Average pig mass (kg)	32.2			215			250		
Total pig mass (kg)	8114.4			3010			93000		

Means of odor concentration and emission were geometric means.

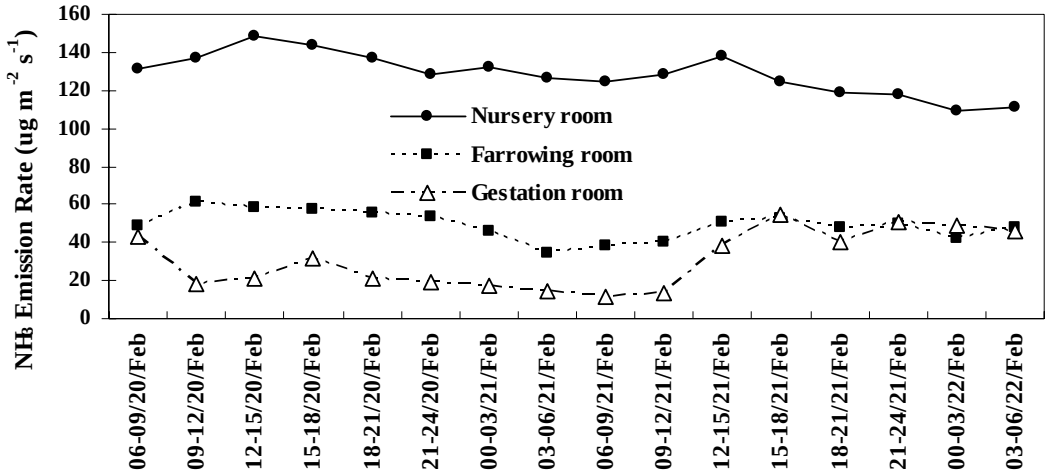
The mean ambient temperature(^oC) : -7.1(S.D. 3.3), Max: -1.6, Min:-14.6

The number of mean: n=16 for all three rooms

5.1.2.2 Gas concentration and emission profiles in February

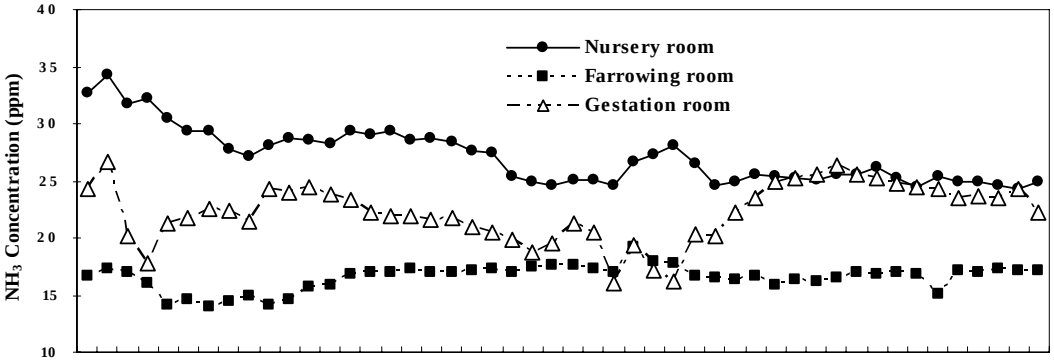


(a) 3-h NH_3 concentrations

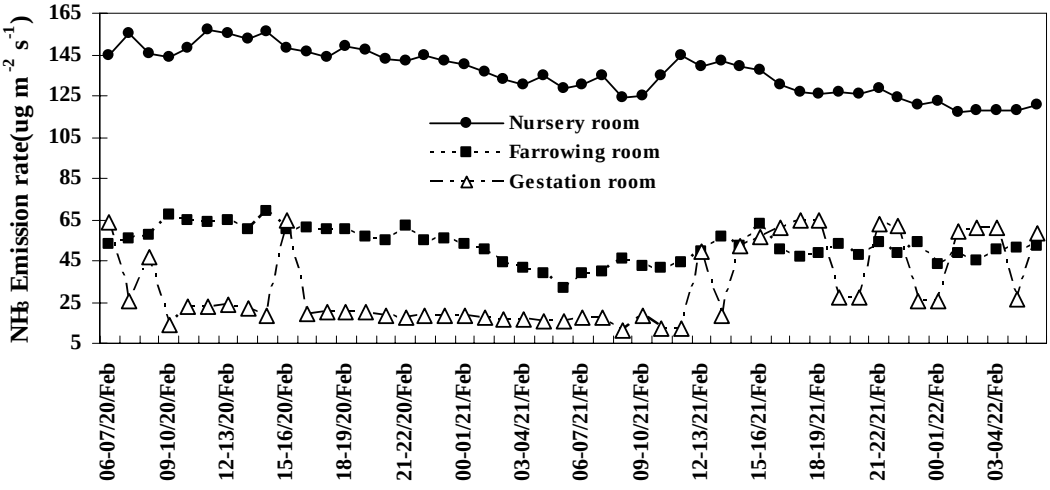


(b) 3-h NH_3 emission rates

Figure 5.1.10 Average 3-h NH_3 concentrations and emissions in February



(a) Hourly NH_3 concentrations

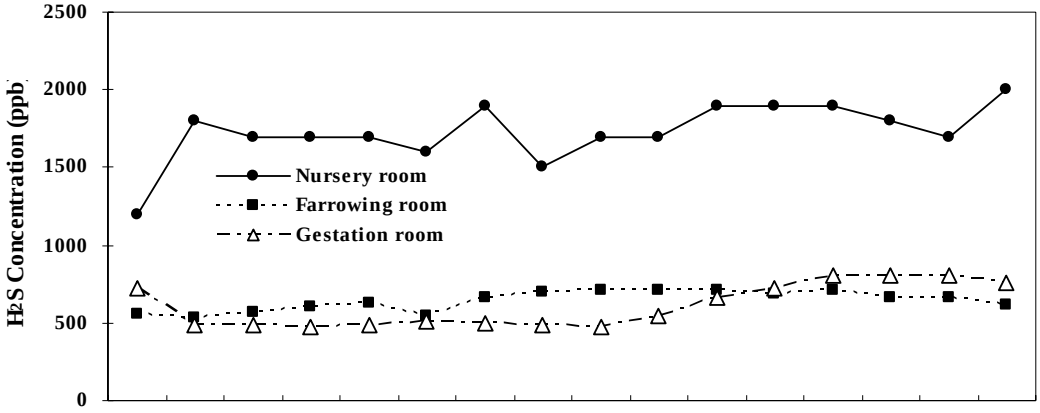


(b) Hourly NH_3 emission rates

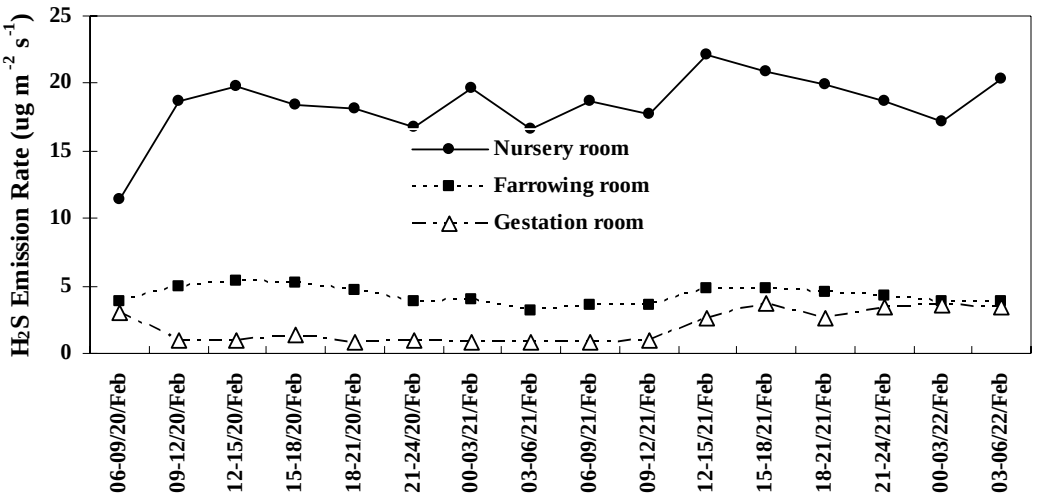
Figure 5.1.11 Hourly NH_3 concentrations and emissions in February

The diurnal variation of NH_3 concentration and emissions, both 3-h and hourly, are plotted in Figures 5.1.10 and 5.1.11. Generally speaking, the variation trend appeared similar for 3-h and hourly profiles. The "diurnal" factor had no significant effect on the variation of NH_3 concentration and emissions (P>0.05) and these values varied in narrow ranges especially for the nursery and farrowing rooms. These small variations were due to the stable ventilation rates of the rooms. The small ventilation rate caused the NH_3 accumulated in the rooms and the concentrations were higher than summer. There were some sharp spikes in hourly emissions in the gestation room because the ventilation rate increased suddenly during those periods. Significant difference of NH_3 concentration and emissions among the rooms were confirmed by statistical analysis (P<0.05) where the mean NH_3 concentrations and emissions in the nursery room were 25.6, 849.3 μg m^{-2} s^{-1}, 15.5 ppm, 748.3μg m^{-2} s^{-1} in the farrowing room, and 21.4 ppm, 167.5μg m^{-2} s^{-1} in the gestation room.

Average 3-h H_2S concentration and emission profiles were demonstrated in Figure 5.1.12 .Due to the malfunction of the H_2S analyzer caused by the harsh air quality in barn, the analyzer was shipped to the manufacturer for recalibration. The H_2S analyzer we used for this testing was the same model as ours and borrowed from University of Manitoba. The bio-security requirement prohibited the analyzer to be taken into the barn, so hourly H_2S concentration data were not obtained.



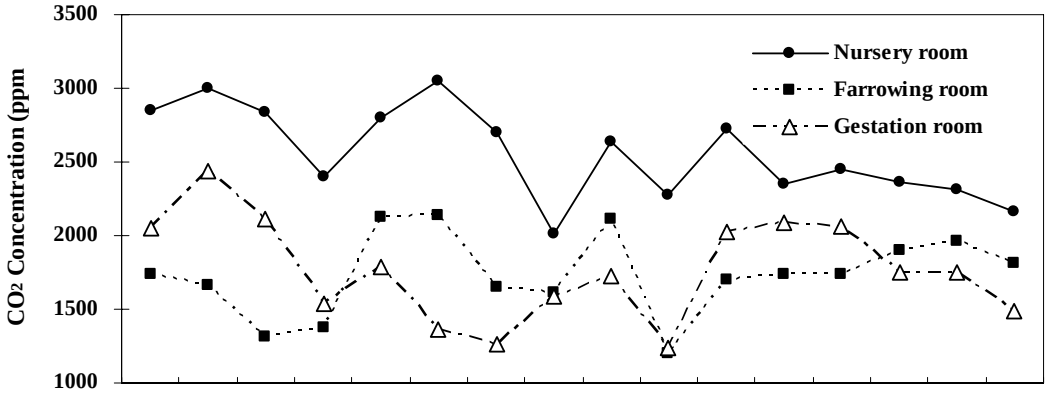
(a) 3-h H_2S concentrations



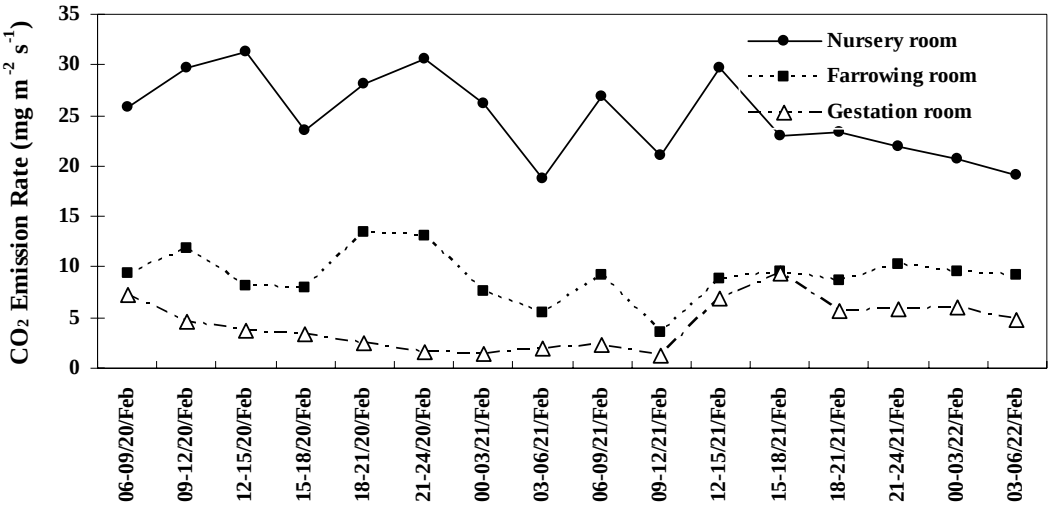
(b) 3-h H_2S emission rates

Figure 5.1.12 Average 3-h H_2S concentrations and emissions in February

From Figure 5.1.12, relatively stable levels of H_2S concentrations and emissions were found. As mentioned previously, the relatively stable levels in all three rooms were related to the stable ventilation rates. Statistical analysis indicated that different room types had different level of H_2S concentrations and emission rates (P<0.05). Nursery had the highest level, followed by farrowing and gestation rooms. The mean concentration and emissions for nursery , farrowing and gestation rooms were 1731 ppb, 18.4 μg m^{-2} s^{-1}; 641 ppb, 4.3 μg m^{-2} s^{-1} and 608 ppb, 1.9 μg m^{-2} s^{-1}, respectively.



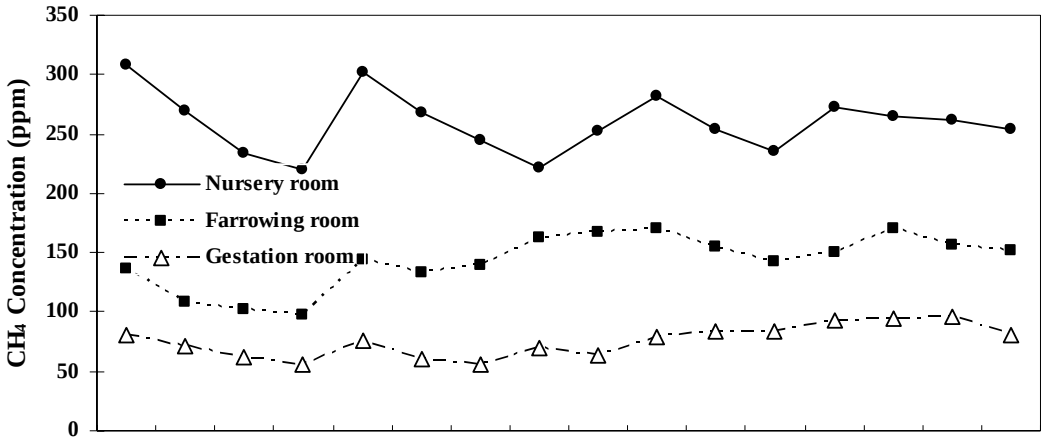
(a) 3-h CO_2 concentrations



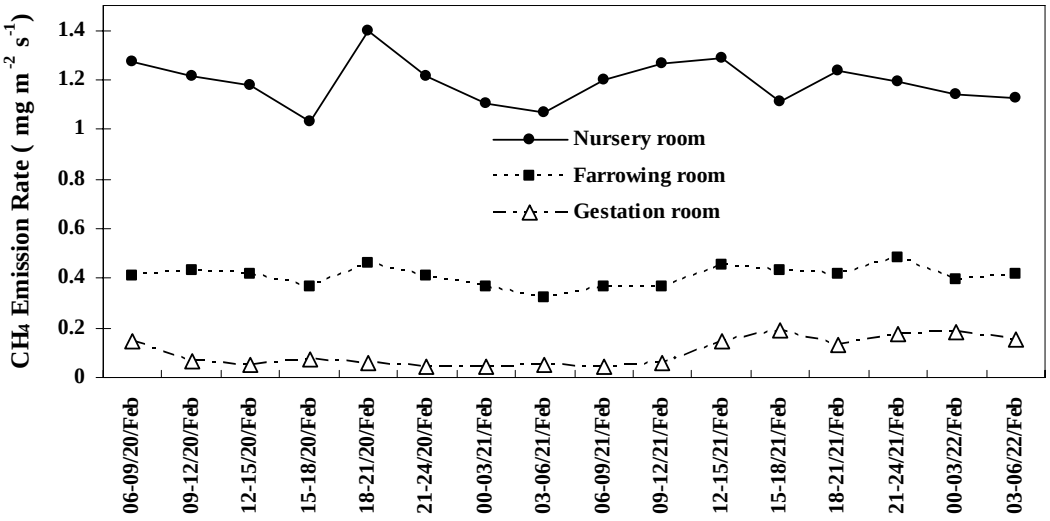
(b) 3-h CO_2 emission rates

Figure 5.1.13 Average 3-h CO_2 concentrations and emissions in February

Average 3-h CO_2 concentrations and emissions are shown in Figure 5.1.13. Because CO_2 concentrations in the nursery room exceeded 3000 ppm which was the measurement limit of the CO_2 analyzer (Guardian Plus Infra-Red Gas Monitor, 0-3000 ppm), it was shut down. There were no hourly CO_2 concentrations in this measurement period. The 3-h average exhaust air was collected from the sampling bags into a 10 ml sample tube using a syringe. Then the sample tubes were transported to Gas Chromatography Laboratory, University of Saskatchewan for CO_2 measurement. There were no significant diurnal variation of CO_2 concentrations and emissions for the February measurement ($P>0.05$) and no apparent fluctuation pattern was discovered. CO_2 emissions showed less variation than CO_2 concentrations because the emissions were also influenced by ventilation rate which were relatively stable. As shown in Figure 5.1.13 and Table 5.1.4, the nursery room had the highest CO_2 concentration and emission rate, followed by the farrowing and gestation rooms. The mean 3-h concentrations and emission rates were 2556 ppm, 25.0 mg m^{-2} s^{-1} for the nursery room, 1737 ppm, 9.1 mg m^{-2} s^{-1} for the farrowing room, and 1766 ppm, 4.3 mg m^{-2} s^{-1} for the gestation room.



(a) 3-h CH_4 concentrations



(b) 3-h CH_4 emission rates

Figure 5.1.14 Average 3-h CH_4 concentrations and emissions in February

The profiles of CH_4 concentration and emissions are laid out in Figure 5.1.14. Obviously, no diurnal variation patterns of CH_4 concentrations and emissions were presented for this February measurement. Small standard deviations of CH_4 concentrations and emissions given in Table 5.1.4 indicated limited fluctuations of the CH_4 concentration and emissions. Similar to the small fluctuations of NH_3 and H_2S concentrations in February, these small variations were associated with the small variations of the ventilation rates. Significant differences of concentrations and emissions between different rooms were found (P<0.05). The CH_4 concentration in the

nursery room was higher than that in the farrowing room and the gestation room had the lowest level. The mean concentrations were 259.1, 143.2 and 75.1 ppm for the nursery, farrowing and gestation rooms, respectively with corresponding mean CH_4 emissions of 1.19, 0.41 and 0.10 mg m^{-2} s^{-1}.

N_2O concentrations were very low in all three rooms with means of 0.34, 0.49, and 0.35 ppm for the nursery, farrowing, and gestation rooms, respectively.

Table 5.1.4 Descriptive statistics on gas concentrations and emissions in February

Variables	Nursery			Farrowing			Gestation		
	Mean(S.D)	Max	Min	Mean(S.D)	Max	Min	Mean(S.D)	Max	Min
NH_3 concentration (ppm)	25.6(2.0)	29	23	15.5(1.0)	17	13	21.4(3.0)	26	15
NH_3 emission(ug m^{-2} s^{-1})	128.6(10.9)	149	110	48.9(7.5)	61.2	34	30.7(15.0)	54	11.8
NH_3 emission (ug AU^{-1} s^{-1})	849.3(72.2)	982	724	748.3(115)	935	526	167.5(82.1)	297	64.6
H_2S concentration (ppb)	1731(192)	2000	1200	641(65)	710	530	608(141)	810	470
H_2S emission (ug m^{-2} s^{-1})	18.4(2.4)	22	11	4.3(0.6)	5.4	3.2	1.9(1.2)	4	0.8
H_2S emission (ug AU^{-1} s^{-1})	121.8(15.9)	147	76	65.2(9.7)	82.3	48.6	10.6(6.5)	21	4.3
CO_2 concentration (ppm)	2556(308)	3044	2008	1737(277)	2136	1206	1766(343)	2438	1234
CO_2 emission (mg m^{-2} s^{-1})	25.0(4.1)	31	19	9.1(2.5)	13.4	3.6	4.3(2.4)	9	1.3
CO_2 emission (mg AU^{-1} s^{-1})	164.8(27.4)	206	124	139.2(37.6)	205	55.1	23.4(13.1)	51	7.1
CH_4 concentration (ppm)	259.1(25.2)	308	220	143.2(23.0)	171	98.2	75.3(13.2)	95	55.2
CH_4 emission (mg m^{-2} s^{-1})	1.19(0.09)	1	1	0.41(0.04)	0.48	0.32	0.10(0.06)	0.2	0.04
CH4 emission (mg AU^{-1} s^{-1})	7.86(0.6)	9	7	6.21(0.64)	7.38	4.9	0.55(0.31)	1.0	0.23
N_2Oconcentration (ppm)	0.34(0.06)	0	0	0.49(0.05)	0.57	0.39	0.35(0.05)	0.5	0.32

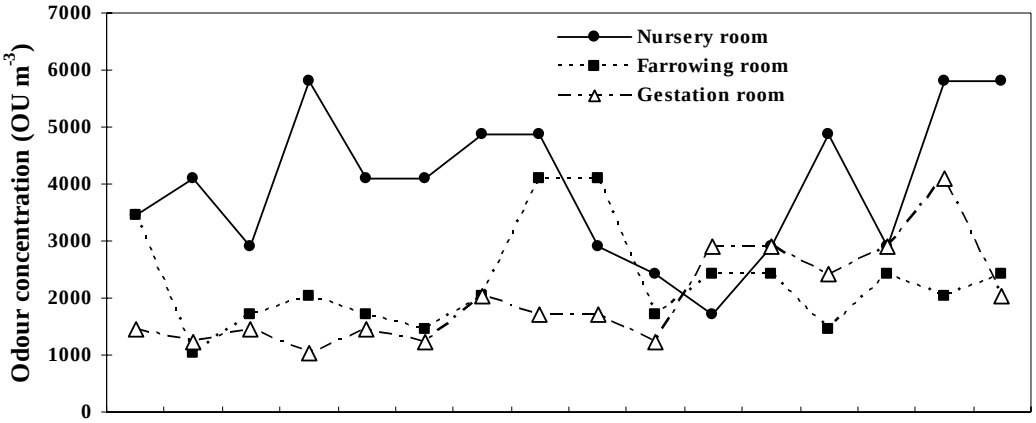
The number of data n=16

5.1.3 Diurnal odour and gas concentration and emission profiles in April

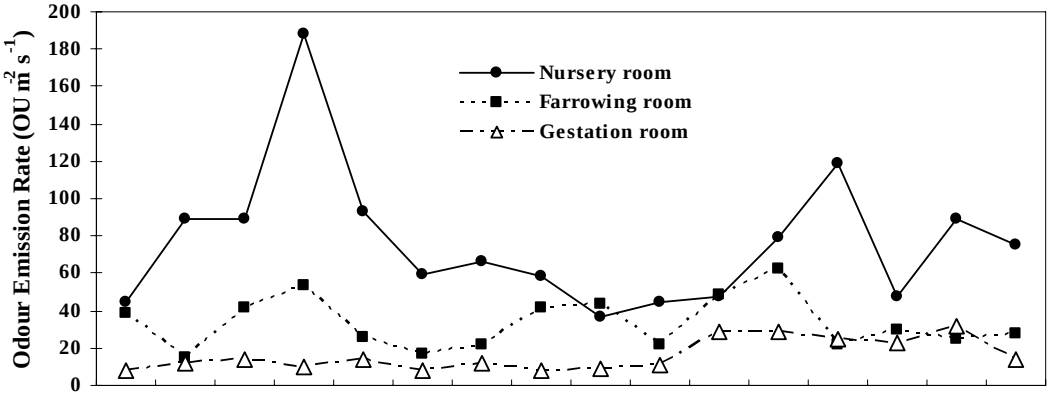
The diurnal measurement under mild climate were carried out from 06:00 am, April 17th, to 06:00 am, April 19th, 2007.

5.1.3.1 Odour and gas concentration and emission profiles in April

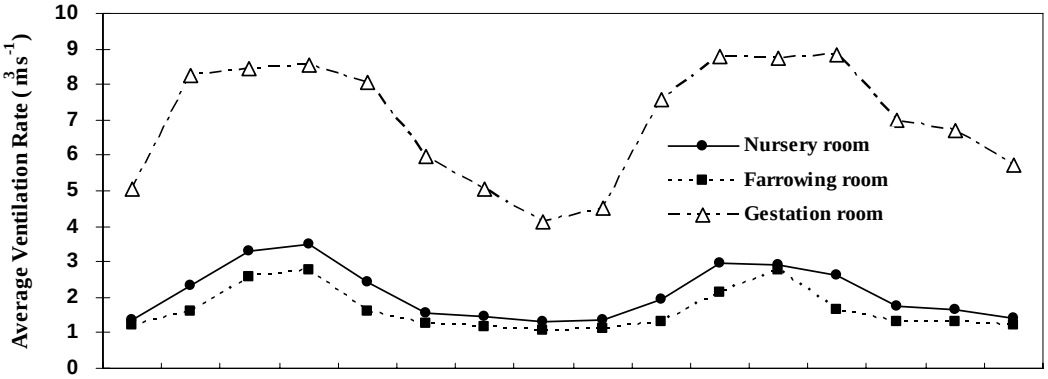
Odour concentrations, emission rates, ventilation rates and inside, ambient temperatures during the testing period are presented in Figure 5.1.15. Basic descriptive statistics mean and standard deviations (S.D) of variables are given in Table 5.1.5.



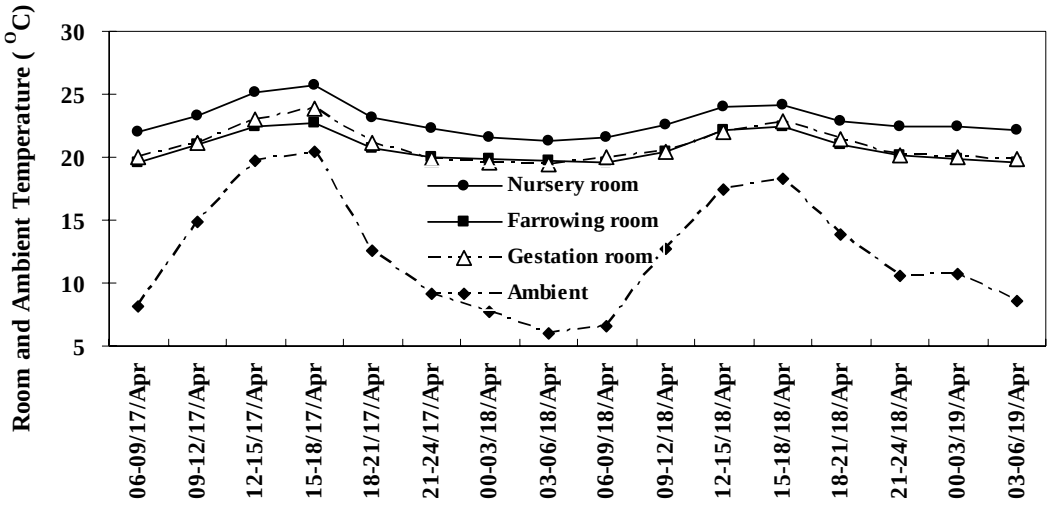
(a) Odour concentrations



(b) Odour emission rates



(c) 3-h average ventilation rates



(d) Room and ambient temperatures

Figure 5.1.15 Average 3-h odour concentrations and emissions in April

As shown in the graphs, odour concentrations fluctuated with time and diurnal factor had significant influence on odour concentration ($P<0.05$). This trend was different from what observed under the winter and summer conditions. For the farrowing room, the diurnal variation displayed a similar pattern in the two consecutive days with the peak falling into the period of 06:00-09:00 h. This high concentration might be caused by the low ventilation rate. However, the low ventilation rates in the nursery and gestation rooms did not always cause odour peaks. The geometric means of 3-h concentrations for the nursery, farrowing and gestation rooms were 3755, 2138, and 1837 OU m^{-3}, respectively. The ratio of max/min concentration was around 4 for all three room. The significant interaction between factor "room type" and "day" on odour concentration ($P<0.05$) indicated that odour concentration in each room differed in two days. The ventilation rate variation trend was closely related to the room temperature as well as the ambient temperature, being high in the late afternoon and low at night. The mean 3-h odour emission rates from the nursery, farrowing, and gestation rooms were 70, 30.7 and 14.2 OU m^{-2} s^{-1}, respectively. Their corresponding odour emissions on animal unit basis were 418.6, 469.8, and 91.1 OU AU^{-1} s^{-1}. The significance of factor "room type" was 0.06, so it still had obvious effect on odour emissions. The statistic analysis demonstrated that only farrowing rooms was significantly influenced by "diurnal" effect

(P<0.05). The peak of the emissions from the nursery room occurred during sampling period 15:00-18:00 h on the first day and 18:00-21:00 h on the second day as the corresponding odour concentration and ventilation rates reached their high levels during those two periods. Furthermore, the odour emission rate from the farrowing room reached its maximum during 15:00-18:00 h for both days when the ventilation rate, ambient temperature and room temperature were all at their peaks. However, the odour emissions from gestation varied in a narrow range comparing with that from the nursery room. In this measurement, the emission ratios of the maximum and minimum values were 5, 4, and 4 respectively, which demonstrated large fluctuation in April.

Table 5.1.5 Descriptive statistics on odour concentrations and emissions in April

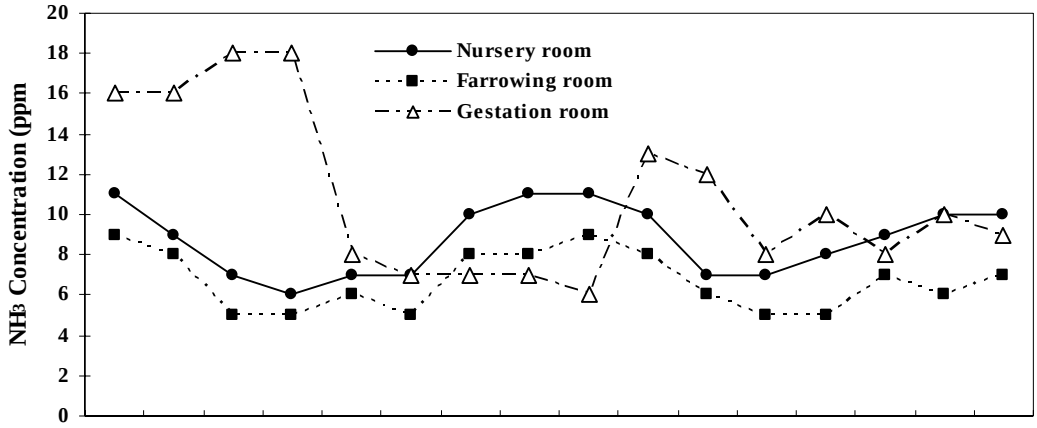
	Nursery			Farrowing			Gestation		
Variable	**Mean(S.D)**	**Max**	**Min**	**Mean(S.D)**	**Max**	**Min**	**Mean(S.D)**	**Max**	**Min**
Odour concentration (OU m^{-3})	3755(1303)	5793	1722	2138(911)	4096	1024	1837(864)	4096	1024
Odour emission (OU m^{-2} s^{-1})	70.0(38.1)	188	36.5	30.7(14.2)	62.8	15.1	14.2(8.6)	31.4	8.1
Odour emission(OU AU^{-1} s^{-1})	418.6(227.8)	1126	218	469.8(217.4)	960	231	91.1(55)	202	51.9
Ventilation rate (m^3 s^{-1})	2.1(0.75)	3.49	1.29	1.62(0.60)	2.78	1.09	6.96(1.67)	8.83	4.11
Room temperature (^oC)	22.9(1.3)	25.7	21.3	20.7(1.1)	22.7	19.5	20.9(1.4)	23.9	19.4
Rom relative humidity (%)	50.4(5.1)	63.3	37.2	45.9(5.9)	57.7	32.4	57.5(6.6)	71.2	42.3
Pig inventory	261			14			317		
Average pig mass (kg)	34.3			250			215		
Total pig mass (kg)	8952.3			3500			68155		

Means of odor concentration and emission were geometric means.

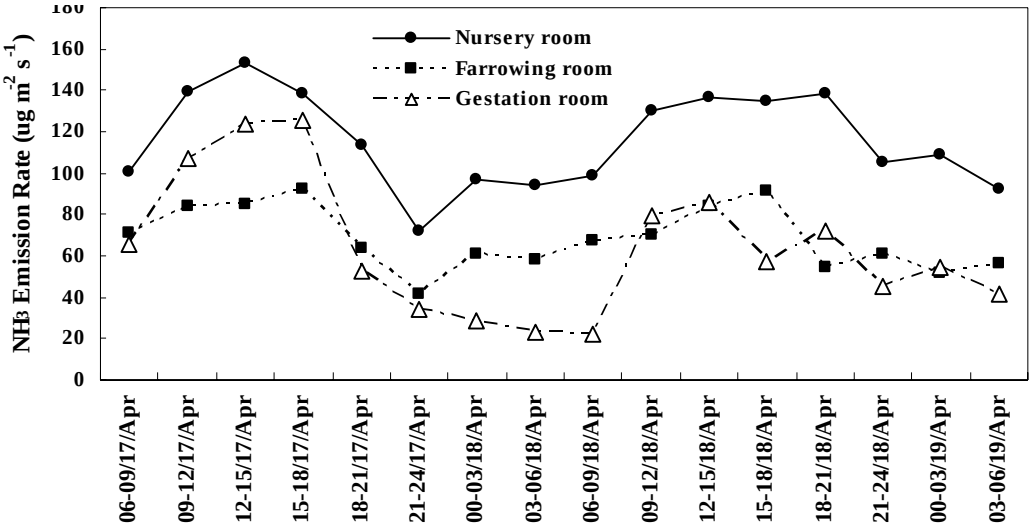
The mean ambient temperature(^oC) : 12.3(S.D. 4.7), Max: 20.4, Min:6.0

The number of data n=16

5.1.3.2 Gas concentration and emission profiles in April

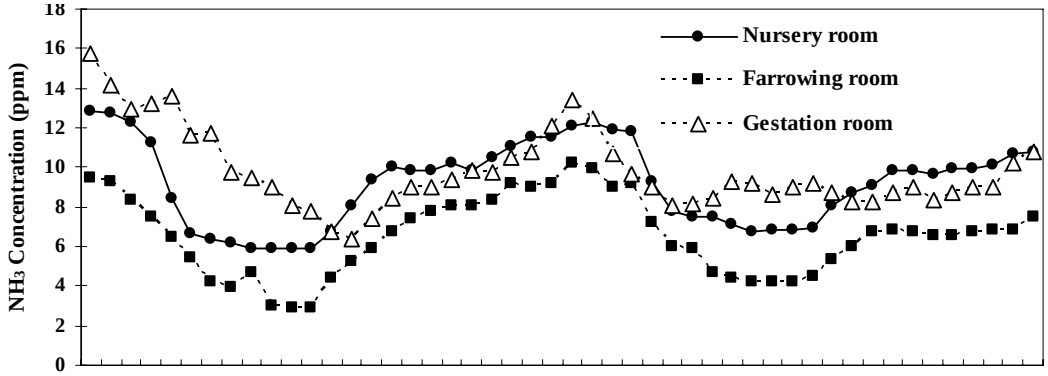


(a) 3-h NH_3 concentrations

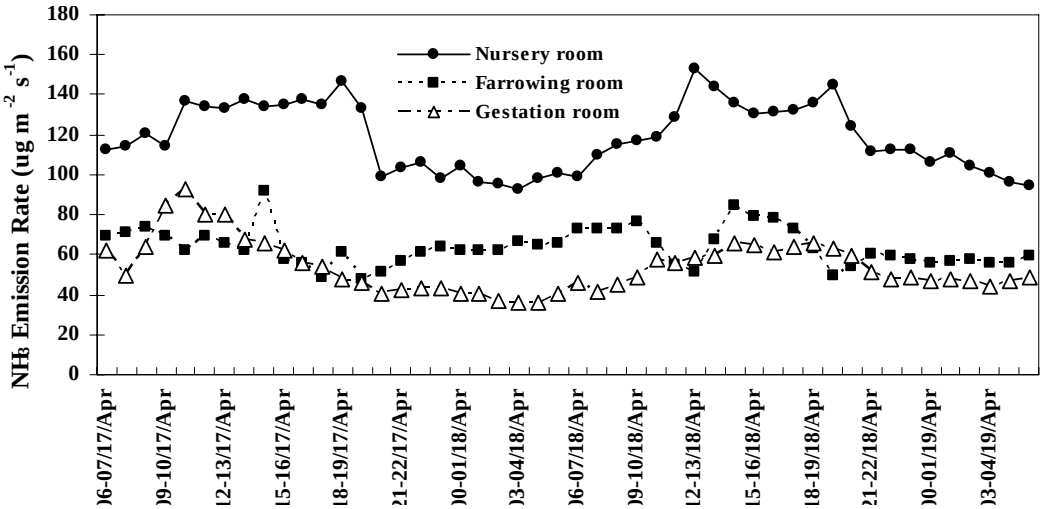


(b) 3-h NH_3 emission rates

Figure 5.1.16 Average 3-h NH_3 concentrations and emissions in April



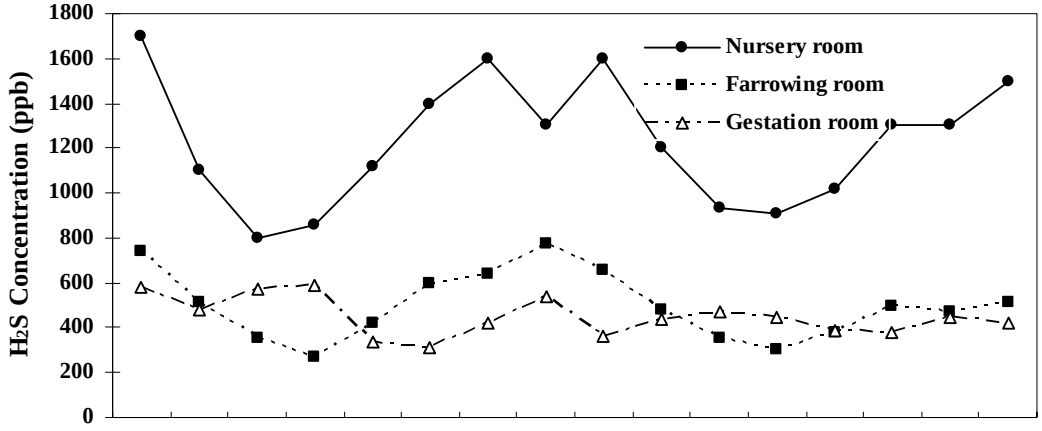
(a) Hourly NH_3 concentrations



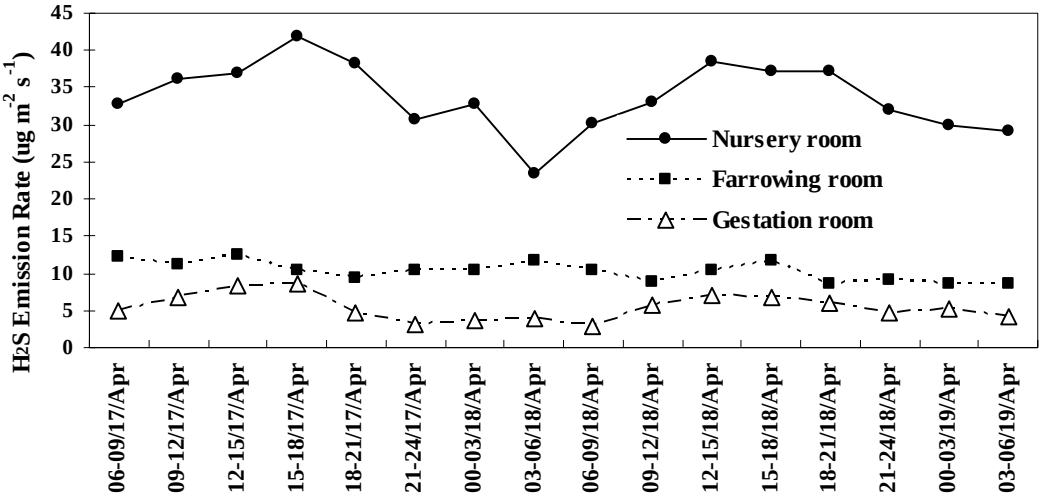
(b) Hourly NH_3 emission rate

Figure 5.1.17 Hourly NH_3 concentrations and emissions in April

The diurnal variation of average 3-h and hourly NH_3 measurements taken from the three rooms are shown in Figures 5.1.16 and 5.1.17. The average 3-h concentration in the gestation room was distinguished from the results of hourly concentrations. During the first day, the average 3-h NH_3 concentration remained at 16 to 18 ppm from 06:00-18:00 h period and then decreased rapidly to 8 ppm and continuously dropped till 09:00 h in the morning. Quite differently, the hourly concentrations in the gestation room decreased gradually and began to rise from 20:00 h. There were no obvious reasons for the difference between these two measurements other than possible measurement mistakes for the 3 h measurements for the gestation room since the 3 h and 1 h concentrations of the other two rooms were similar. The diurnal variation profiles of the hourly NH_3 concentrations of the three rooms were similar, low during the day and high at night. Diurnal factor had no significant effect on NH_3 concentration due to abnormal fluctuation of the gestation room (P>0.05). However, if each room was analyzed separately, the "diurnal" factor had significant effect on NH_3 concentration in the nursery and farrowing rooms (P<0.05). For NH_3 emissions, both "room type" and "diurnal" factors had statistically significant effect on the emissions (P<0.05). The emissions fluctuated considerably over time. The variation trends of the three rooms were similar to those of the ventilation rates, although the concentration varied inversely. This indicates that the ventilation rate was the dominant factor in emission rate under April weather condition with large temperature fluctuations. Table 5.1.6 gives the statistical summary of the NH_3 emissions, which were 115.9, 68.3 9 and 63.7 9 μg m^{-2} s^{-1} for the nursery, farrowing and gestation rooms, respectively.



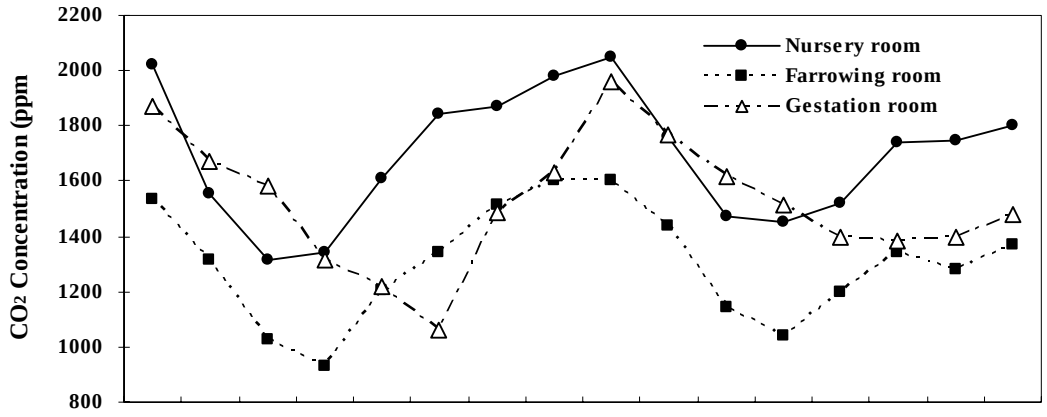
(a) 3-h H_2S concentrations



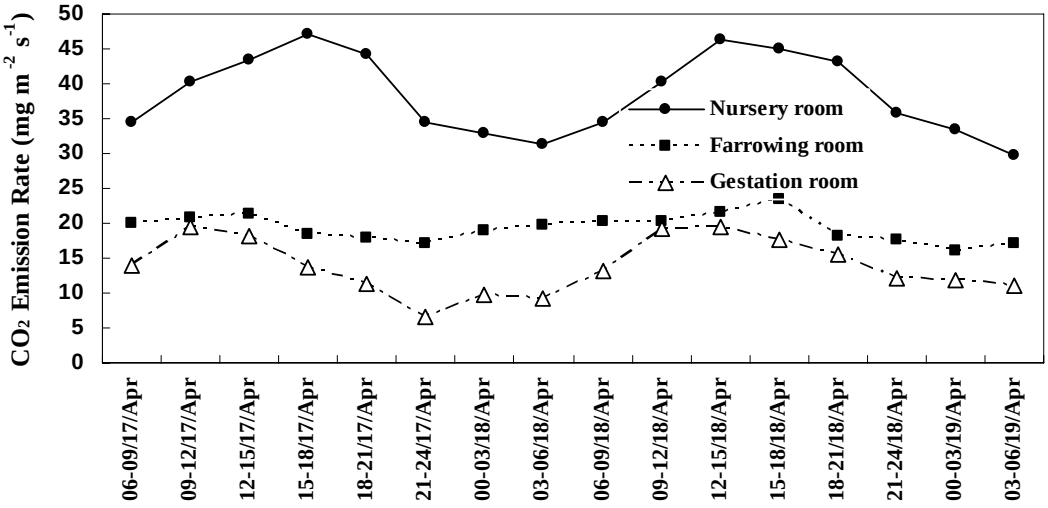
(b) 3-h H_2S emission rates

Figure 5.1.18 Average 3-h H_2S concentrations and emissions in April

Average 3-h H_2S concentrations and emissions in April are plotted in Figure 5.1.18. Because the H_2S analyzer was borrowed again so it could not be taken into the barn for bio-security reason, the hourly concentration was not obtained. For the nursery and farrowing rooms, low concentrations were corresponding to high ventilation rates and vice versa. For the gestation room, the concentrations during 12:00-18:00 h were a little higher than the other periods for both two days, which was unusual but similar to the 3-h NH_3 concentrations as discussed previously. The reason was unknown. H_2S concentrations and emissions differed significantly between rooms and sampling periods (P<0.05). Statistical results manifested that H_2S emissions varied diurnally under mild conditions. Less variation of H_2S emissions than concentrations proved the dominant role of ventilation rate in determination of emissions. The mean concentrations and emissions in the nursery room were 1227.5 ppb, 33.8 μg m^{-2} s^{-1}, 496.9 ppb, 10.3 μg m^{-2} s^{-1} in farrowing, and 449.4 ppb, 5.4 μg m^{-2} s^{-1} in the gestation room.

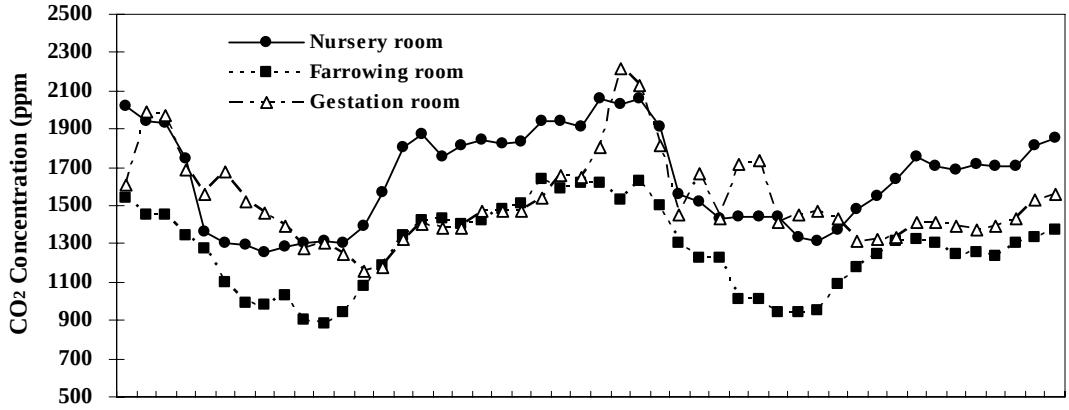


(a) 3-h CO_2 concentrations

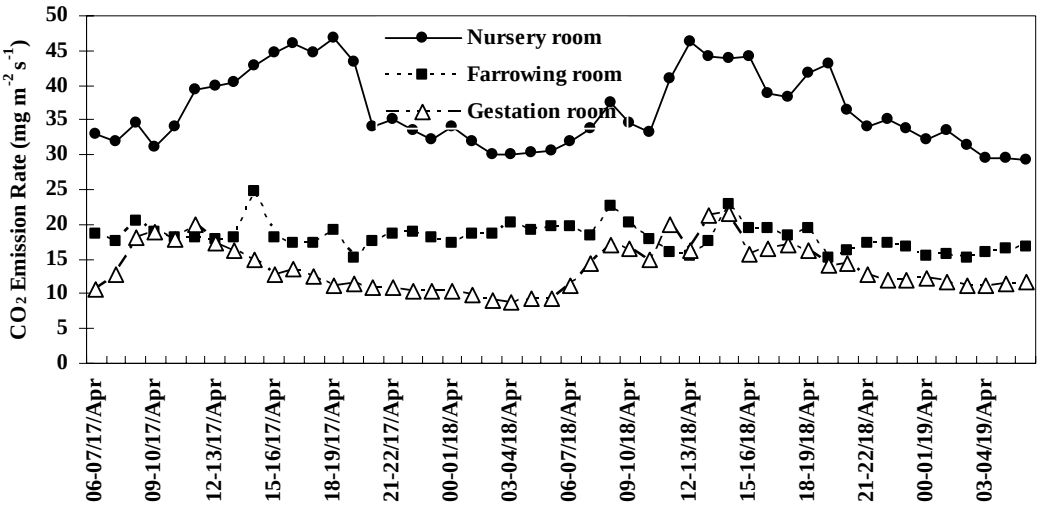


(b) 3-h CO_2 emission rates

Figure 5.1.19 Average 3-h CO_2 concentrations and emissions in April



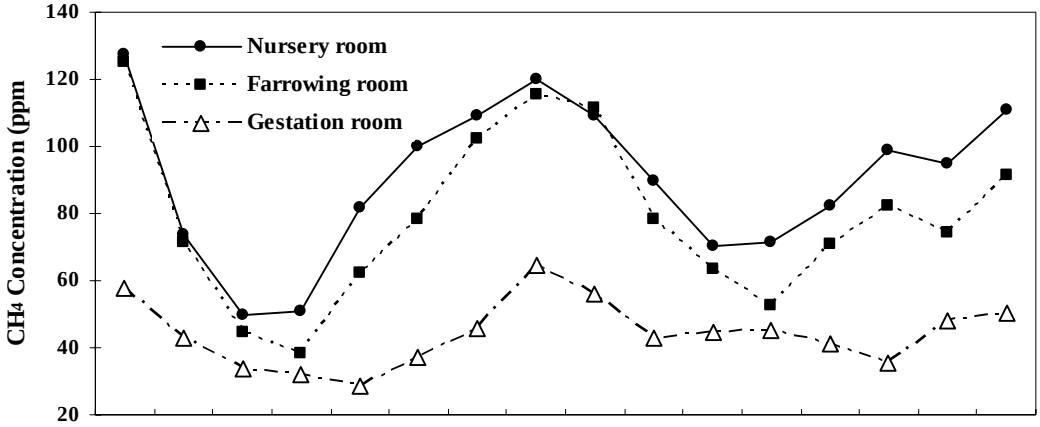
(a) Hourly CO2 concentrations



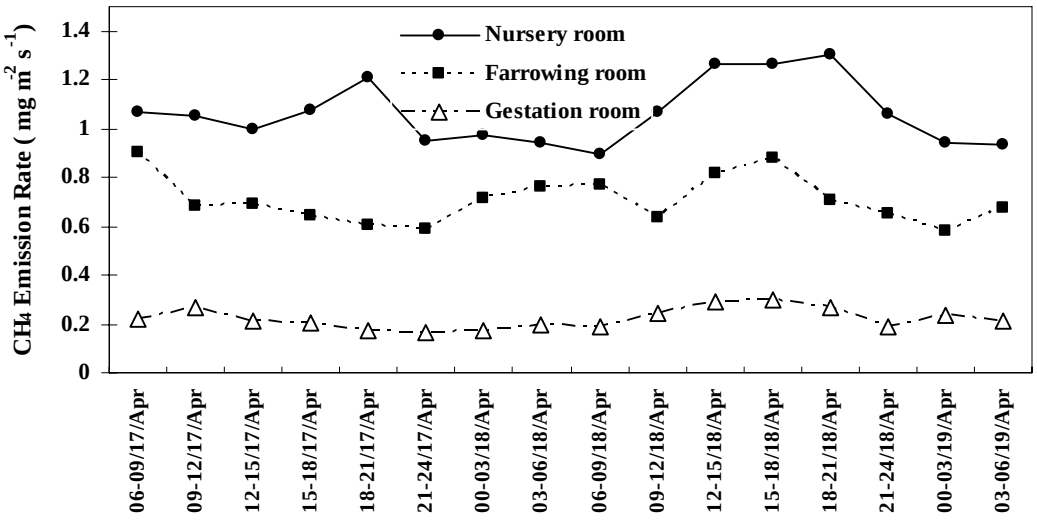
(b) Hourly CO_2 emission rates

Figure 5.1.20 Hourly CO_2 concentrations and emissions in April

Figures 5.1.19 and 5.1.20 show the fluctuation of 3-h CO_2 concentrations and emissions and hourly profiles as well. The curves of the 3-h and 1-h for each room were fairly similar. The CO_2 concentrations fluctuated over time and generally low with high ambient temperature and high with low ambient temperature. The peaks occurred during 06:00-09:00 h for all three rooms in two days. For the lowest level, different room types had different time, e.g. the nursery and farrowing rooms fell into the 12:00-18:00 h period while the gestation 21:00-24:00 h by unknown reasons. The mean 3-h average concentrations were 1693, 1305, and 1522 ppm for the nursery, farrowing and gestation rooms. Furthermore, diurnal trend of CO_2 emissions from the rooms were the opposite of that of CO_2 concentration but similar to the trend of ventilation rate, which indicated that the ventilation rate varying in a large range under the April climate was the dominant factor in emissions.



(a) 3-h CH_4 concentrations



(b) 3-h CH_4 emission rates

Figure 5.1.21 Average 3-h CH_4 concentrations and emissions in April

Figure 5.1.21 provided the profiles of diurnal variation of CH_4 concentrations and emissions in April. The "diurnal" factor had significant impact on the CH_4 concentrations for all three rooms (P<0.05). Apparent diurnal variation patterns presented in the daily course that the CH_4 concentration decreased with the increasing of ambient temperatures and vice versa. The concentration approached the peak at 03:00-06:00 h for all three rooms. However, the "diurnal" factor had no significant effect on the CH_4 emission (P>0.05) as the emissions varied within a small range. The "room type" factor had significant effect on the CH_4 concentration and emissions under mild weather condition (P<0.05). The mean CH_4 concentrations were 90.1, 78.9, and 38.1

ppm in the nursery, farrowing and gestation rooms, respectively; their corresponding emission rates were 1.06, 0.71, and 0.22 mg m^{-2} s^{-1}, respectively.

Table 5.1.6 Descriptive statistics on gas concentrations and emissions in April

Variables	Nursery			Farrowing			Gestation		
	Mean(S.D)	Max	Min	Mean(S.D)	Max	Min	Mean(S.D)	Max	Min
NH_3 concentration (ppm)	8.8(1.7)	11	6	6.7(1.5)	9	5	10.8(4.2)	18	6
NH_3 emission(ug m^{-2} s^{-1})	115.9(23.1)	153	72.5	68.3(15.3)	92.2	41.5	63.7(33.3)	125	22
NH_3 emission (ug AU^{-1} s^{-1})	692.7(137.8)	916	433	1043.9(234.0)	1410	634	408.2(213.7)	803	141
H_2S concentration (ppb)	1227.5(282.8)	1700	800	496.9(151.8)	770	270	449.4(85.8)	590	310
H_2S emission (ug m^{-2} s^{-1})	33.8(4.6)	42	23.5	10.3(1.3)	12.6	8.5	5.4(1.8)	8.7	2.8
H_2S emission (ug AU^{-1} s^{-1})	201.9(27.5)	251	141	157.8(20.5)	193	130	34.6(11.3)	55.6	17.9
CO_2 concentration (ppm)	1692.8(234.7)	2050	1315	1305(205.9)	1605	930	1522.5(234.2)	1960	1060
CO_2 emission (mg m^{-2} s^{-1})	38.5(5.8)	47.1	29.7	19.3(1.9)	23.4	16.2	13.9(4.0)	19.6	6.5
CO_2 emission (mg AU^{-1} s^{-1})	230.1(34.7)	282	178	294.7(29.7)	358	247	89.4(25.7)	126	41.5
CH_4 concentration (ppm)	90.1(23.0)	128	49.9	78.9(25.1)	125	38.1	44.1(9.7)	64.5	28.8
CH_4 emission (mg m^{-2} s^{-1})	1.06(0.13)	1.29	0.89	0.71(0.10)	0.91	0.58	0.22(0.04)	0.29	0.17
CH4 emission (mg AU^{-1} s^{-1})	6.35(0.78)	7.77	5.34	10.80(1.49)	13.8	8.88	1.41(0.27)	1.89	1.07
N_2Oconcentration (ppm)	0.38(0.02)	0.41	0.33	0.57(0.10)	0.82	0.44	0.41(0.02)	0.46	0.38

The number of data n=16 for all three rooms

5.1.4 Summary of diurnal odour and gas concentrations and emissions

The means of diurnal odour, NH_3, H_2S, CO_2 and CH_4 concentrations and emissions in the three rooms during three sampling seasons are illustrated in following figures from Figure 5.1.22 to Figure 5.1.26. Because the level of N_2O was so low with small variation that it was not included hereafter. The statistical summary was presented in Table 5.1.7.

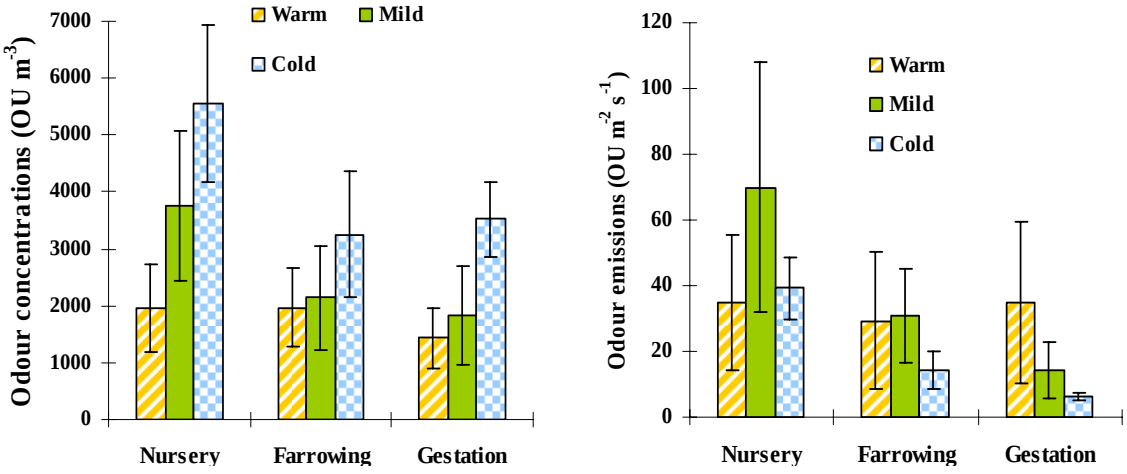


Figure 5.1.22 Means of diurnal odour concentrations and emissions from three types of rooms

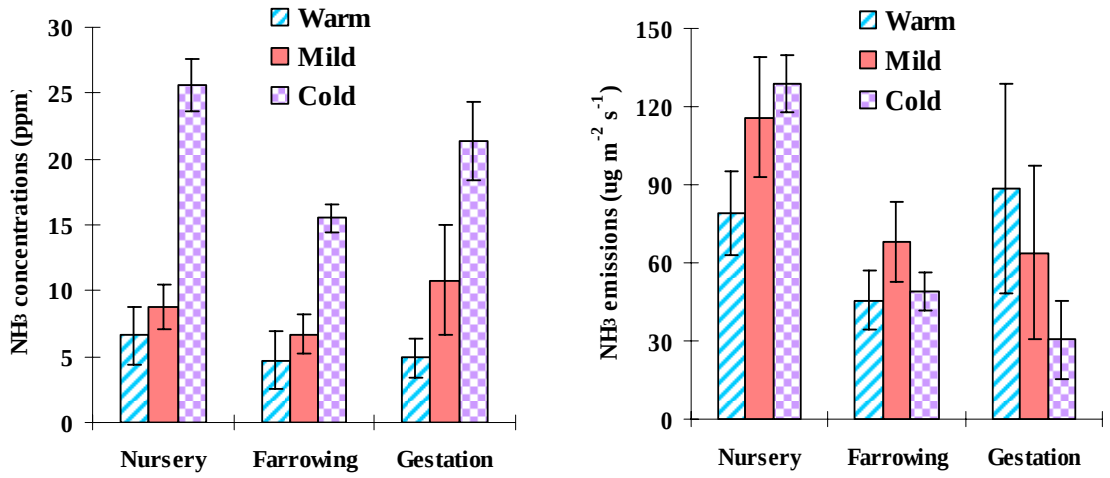


Figure 5.1.23 Means of diurnal NH_3 concentrations and emissions from three types of rooms

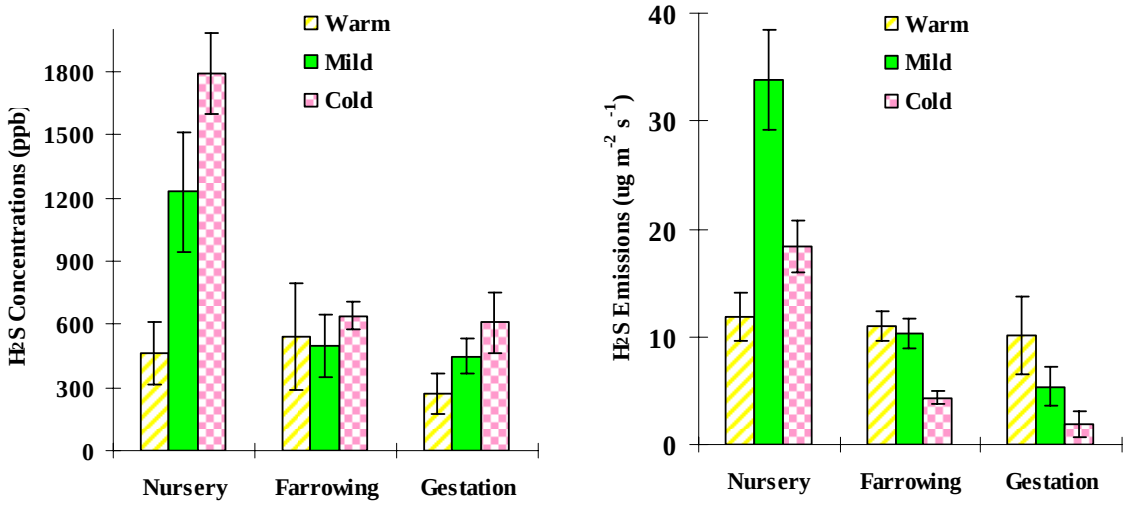


Figure 5.1.24 Means of diurnal H_2S concentrations and emissions from three types of rooms

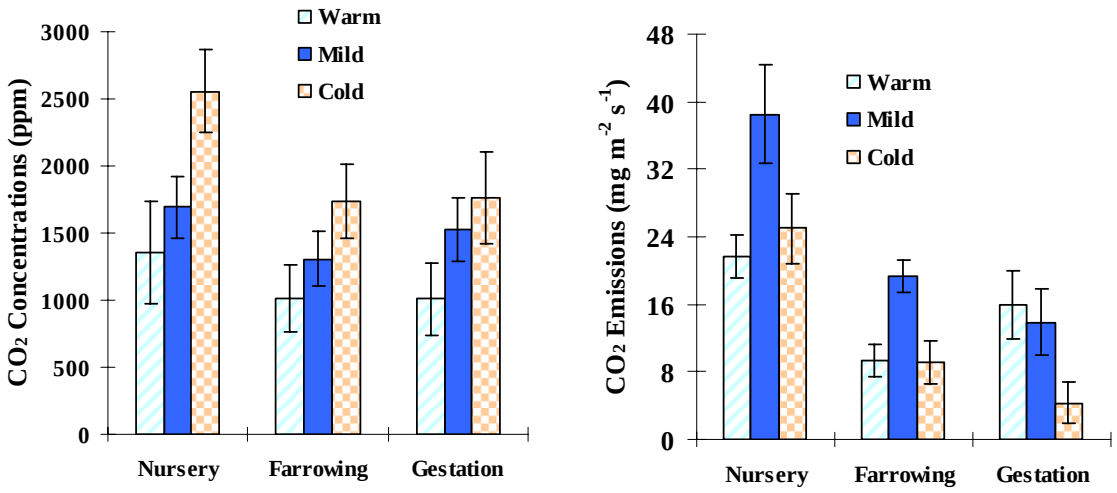


Figure 5.1.25 Means of diurnal CO_2 concentrations and emissions from three types of rooms

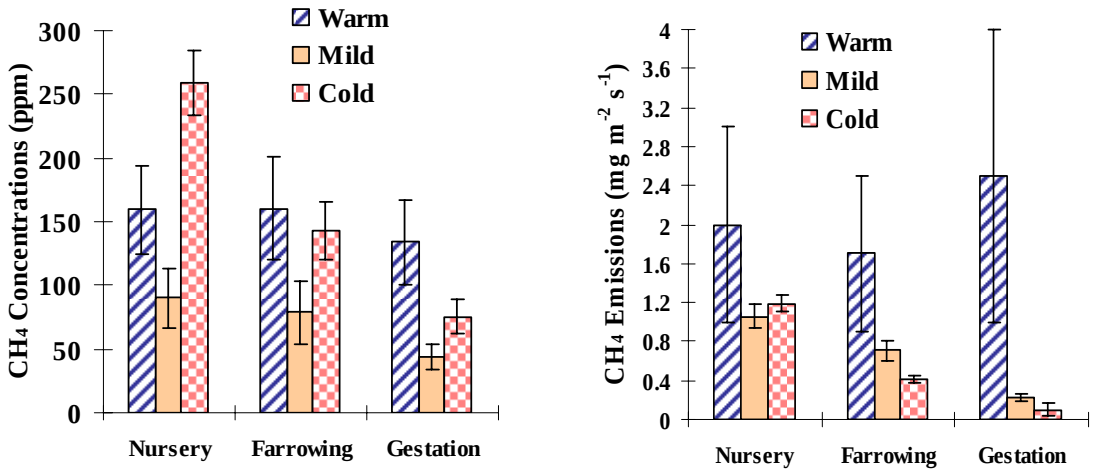


Figure 5.1.26 Means of diurnal CH_4 concentrations and emissions from three types of rooms

Generally speaking, the odour and gas concentrations and emissions in nursery were higher than those in farrowing and gestation rooms for all three seasons. This distinction was mainly attributed to the nursery physiological and behavioural characteristics, diet, and high room temperature, which cause higher odour and gas production. Firstly, the diet and feed for nursery room were different from other two types of room which produced the waste releasing high level of odour and gases. Secondly, the room

temperature in nursery was set higher and induced more odour and gases generation. Additionally, the manure removal schedule might also influence the odour and gas production. For nursery, the manure was pumped out on an 8-week basis, while the waste in farrowing and gestation was removed every 3 weeks. The longer the manure stayed in the pit, the more odour and gas generated within the buildings. During the measurement periods, we also investigated the animal activity of each room. It was found that nursery pigs were very active and sensitive and they were easily affected by the activities of the workers. The high level of exercise of nursery pigs would also increase the dust concentration in the room, which would result in increase of odour and gas concentrations because the dust is a carrier of odour and gas.

The odour and gas concentrations in winter had the highest level, they were lower under mild weather in April, and the lowest level occurred in August. These odour and gas characteristics applied for all three rooms except for CH_4 concentration. The primary reasons lied on the large difference of ventilation rates and ambient temperatures in different seasons. Low concentrations under warm weather conditions were mainly attributed to the strong dilution effect of high air exchange rate. By contrast, low ventilation rate in the cold season caused the accumulation of odour and gas inside the rooms. It was interesting to address that the variation pattern of NH_3, H_2S, CO_2 and CH_4 concentrations in August and April were closely related to the variation patterns of the ventilation rate and ambient temperature, especially in August. High level happened in the early morning and night while the low occurred in late morning and the afternoon. The variation pattern was the opposite of those of the ventilation rate and ambient temperature. However, the concentrations in February were maintained at relatively steady level and varied within a small range because the ventilation rates did not vary much.

The variations of odour concentration for all three rooms in three different seasons seemed random without specific patterns. Some spikes were observed during the daily course, which was difficult to explain. Some studies reported that it was caused by animal or worker's activities during or prior to the sampling periods (Sun, 2005; Zhu et

al., 2000). The higher level of animal activities resulted from the stockman's working activities such as feeding, treating or moving animals, or cleaning in the barn would increase odour and gas production.

For odour and gas emissions, the emission from the nursery room were higher than the farrowing and gestations rooms in general based on per square meter of floor area. The results obtained were comparable with other studies (Zhu et al., 2000). There was no significant difference between the farrowing and gestation rooms in odour and gas emissions (P>0.05) because the pigs had similar diet and the other distinctions were that the temperature in the farrowing room was 1 to 2^{o}C higher than the gestation room and the pig density in the gestation room was higher than the farrowing room (84 vs 33 kg m^{-2}). When comparing the odour and gas emissions between the three sampling seasons, the highest levels occurred in different seasons for different rooms. Taking odour emission for example, the higher emission occurred in April for the nursery and farrowing rooms, while in August for the gestation room. For NH_3 emissions, the nursery room had the highest level in February, while the farrowing room in April and the gestation room in August, although the concentrations reached the highest levels for all three rooms in February. This is because the emission rate was the product of concentration and ventilation rate, these two factors had an inverse relationship and both factors varied in large ranges in mild and warm seasons except for winter. As discussed previously, the variation pattern of odour and gas emissions could be predicted under three conditions: 1) if concentration kept relatively constant, the variation pattern were mainly dependent on the trend of ventilation rate; 2) if the ventilation rate remained steady, the variation trend of concentration predominated the emission pattern; 3) if both concentration and ventilation rate fluctuated in large ranges such as under mild climate, the emission pattern would not be obvious.

Scheffe multiple comparison was performed to compare the means of odour and gas concentrations and emissions for three measurement seasons. The results were displayed in Table 5.1.7.

Table 5.1.7 Means comparison of odour and gas concentrations and emissions during three measurement seasons

Variables	Months	Nursery	Farrowing	Gestation
Odor concentration	Aug--Feb	S	S	S
	Feb--Apr	S	S	S
	Aug--Apr	S	NS	NS
Odor emission rate	Aug--Feb	NS	S	S
	Feb--Apr	S	S	NS
	Aug--Apr	S	NS	S
NH_3 concentration	Aug--Feb	S	S	S
	Feb--Apr	S	S	S
	Aug--Apr	S	S	S
NH_3 emission rate	Aug--Feb	S	NS	S
	Feb--Apr	S	S	S
	Aug--Apr	S	S	S
H_2S concentration	Aug--Feb	S	NS	S
	Feb--Apr	S	S	S
	Aug--Apr	S	NS	S
H_2S emission rate	Aug--Feb	S	S	S
	Feb--Apr	S	S	S
	Aug--Apr	S	NS	S
CO_2 concentration	Aug--Feb	S	S	S
	Feb--Apr	S	S	S
	Aug--Apr	S	S	S
CO_2 emission rate	Aug--Feb	S	S	S
	Feb--Apr	NS	NS	NS
	Aug--Apr	S	S	S
CH_4 concentration	Aug--Feb	S	NS	S
	Feb--Apr	S	S	S
	Aug--Apr	S	S	S
CH_4 emission rate	Aug--Feb	S	S	S
	Feb--Apr	NS	NS	NS
	Aug--Apr	S	S	S

Note: "S" means the concentrations and emissions between two measuring months differed significantly; "NS" means there were no significant difference between two months

As shown in Table 5.1.7, significant difference of odour and gas concentrations and emissions were observed under different weather conditions in all three rooms for most cases (P<0.05). Furthermore, Table 5.1.8 provided the effects of “diurnal” factor on odour and gas concentrations and emissions in three sampling months for the three rooms. In August and April, the diurnal factor significantly influenced some odour and gas concentrations and emissions (46.6% of the odour and gas concentrations and

emissions were significantly affected by the “diurnal” factor). However, in February, the “diurnal” factor had no significant effect on all odour and gas concentrations and emissions except CH_4 emission rate, due to the stable indoor environment in winter. Since the “diurnal” factor had significantly effects on odour and gas concentrations and emissions, it was essential to take the diurnal variation into consideration in odour or gas dispersion modeling. Randomly measured emissions that were utilized in odour dispersion model could contribute to large uncertainty in setback distance predictions.

Table 5.1.8 Effects of diurnal factor on odour and gas concentrations and emissions during three sampling seasons

Variables	August			February			April		
	N	F	G	N	F	G	N	F	G
Odour concentration	NS	NS	S	NS	NS	NS	NS	S	NS
Odour emission	NS*	S	S	NS	NS	NS	NS	S	NS
NH_3 concentration	S	NS	S	NS	NS	NS	S	S	NS
NH_3 emission	NS*	NS	NS*	NS	NS	NS	S	S	NS
H_2S concentration	S	NS*	S	NS	NS	NS	S	S	NS
H_2S emission	NS	NS	NS	NS	NS*	NS	S	NS	S
CO_2 concentration	NS	S	S	NS	NS	NS	S	S	S
CO_2 emission	NS	NS	S	NS	NS	NS	S	NS	S
CH_4 concentration	NS	NS	NS	NS	NS	NS	S	S	S
CH_4 emission	NS	NS	NS	S	NS	NS	NS	NS	NS

Note: "S" means diurnal factor had significant effect on concentrations and emissions; "NS" denotes diurnal factor had no significant effect. "NS*" means p>0.05, but pretty close to 0.05; N denotes nursery room, F denotes farrowing room, and G denotes gestation room

5.1.5 Dust concentration and dust deposition in diurnal measurements

Total dust concentrations measured in three diurnal measurements were taken from 08:00 to 16:00 h for 2 consecutive days. The 8-h measurements represented dust conditions over the 8 hour period for the barn workers. Table 5.1.9 provides the dust concentration results under the three climate conditions. For the nursery room, the total dust concentration in mild weather had the highest level, followed by the cold and warm conditions. However, the farrowing and gestation rooms in cold weather had higher level than warm and mild conditions. The total dust concentrations in warm weather always stayed at the lowest level which was related to the high ventilation rate.

Comparing the three rooms, the total dust concentration of the nursery room was much higher than that of the other two types, which might be caused by active nursery pigs that generated more airborne particulates within the room.

Table 5.1.9 Total dust concentration in three diurnal measurements

Climate	Day	Total dust concentration (mg m^{-3})			Average (mg m^{-3})		
		Nursery	Farrowing	Gestation	Nursery	Farrowing	Gestation
Warm	Day 1	0.9	0.23	0.82	1.07	0.20	0.75
	Day 2	1.23	0.16	0.68			
Cold	Day 1	3.8	1.3	1.21	3.36	1.40	1.22
	Day 2	2.92	1.49	1.22			
Mild	Day 1	4.16	0.98	0.79	4.44	1.06	0.65
	Day 2	4.72	1.14	0.51			

Regarding to the dust deposition, Figure 5.1.31 shows the results. The nursery room had much higher level than the other two rooms, which was due to the high total dust concentration (P<0.05). No significant difference of dust deposition was observed between the farrowing and gestation rooms (P>0.05). Dust depositions under warm weather were at the lowest levels for all three rooms due to high ventilation rate in warm weather.

Table 5.1.10 Dust deposition in three diurnal measurements

Climate	Dust deposition (mg m^{-2} h^{-1})		
	Nursery	Farrowing	Gestation
Warm	35.72	6.37	14.86
Cold	101.2	25.7	33.9
Mild	105	19.5	20.6

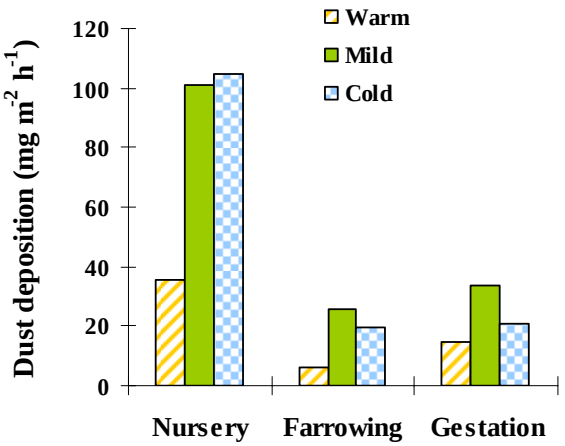


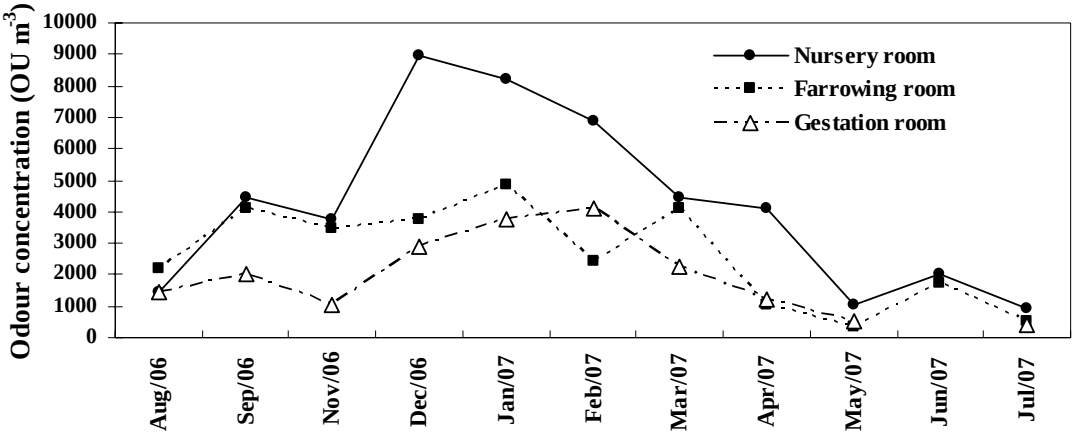
Figure 5.1.27 Dust deposition for the three diurnal measurements

5.2 Seasonal Odour and as Concentration ad Emission Profiles

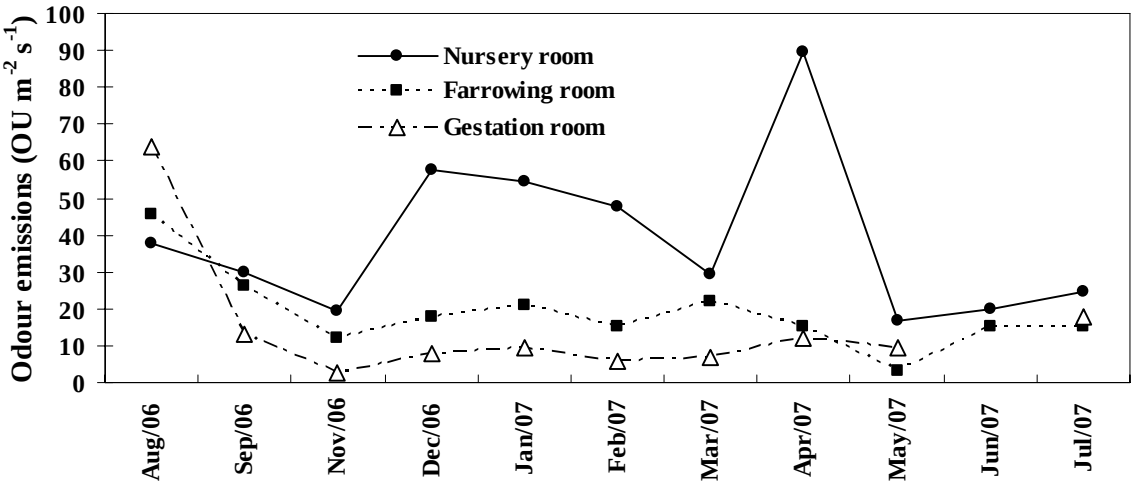
Seasonal odour and gas measurements were taken for one year, once a month from August 2006 to July 2007. All the measurements were intended to be taken around the 20th day of each month in order to make the results comparable among different months. However, due to unavailability of the Olfactometry Laboratory service on the weekends and absence of pigs during room cleaning period, some measurements were taken prior to or after the 20^{th} of the months. Odour measurements were taken during the daytime from 09:00 to 12:00 h when high pig and worker activities were taking place. Two identical odour samples were collected by continuously pumping the exhaust air into the sample bags for three hours representing average 3-h concentration and then transported to the Olfactometry Laboratory for measurement within 30 hours after the samples were collected. The NH_3, H_2S and CO_2 concentrations from each room were measured hourly for three days in each month. However, there were some missing data of H_2S and CO_2 in some months due to bio-security concerns for the lent H_2S analyzer or limited measurement span for the CO_2 analyzer. The H_2S analyzer was borrowed from University of Manitoba for 3 months due to the malfunction of our own analyzer and it could not be taken into the barn due to bio-security policy, so hourly data could not be obtained. We could only measure average 3-h H_2S concentrations from the odour sampling bags. Meanwhile, when CO_2 exceeded the measurement range of 3000 ppm of the CO_2 analyzer in winter, CO_2 concentration was measured from the odour sampling bags together with CH_4 and N_2O concentrations by the GC Laboratory. In this case, we only obtained the average 3-h (09:00 to 12:00 h) results of odour and gas odour concentrations and emissions.

5.2.1 Seasonal odour and gas concentration and emission profiles

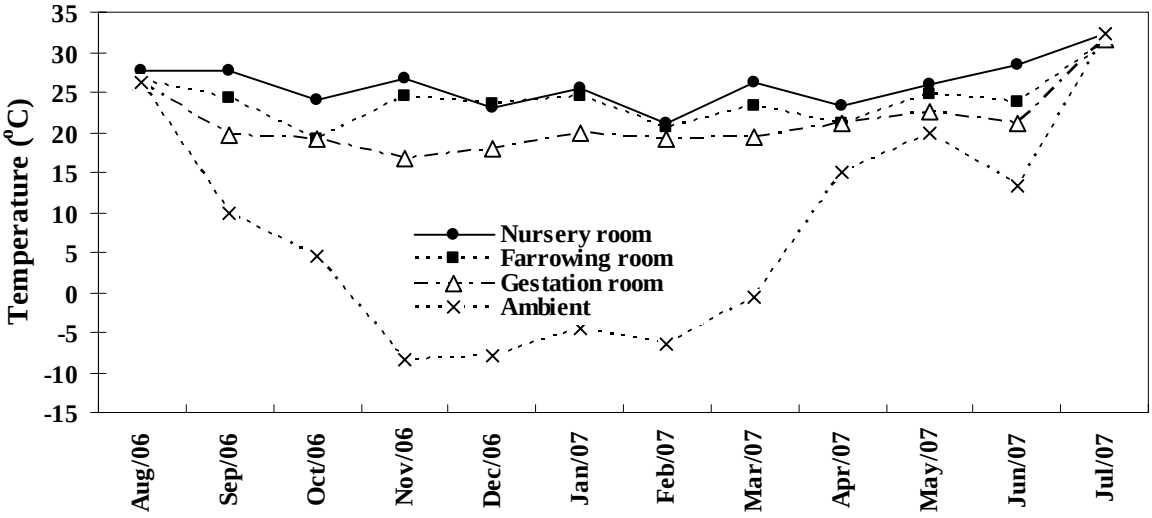
Measured annual variations of odour concentrations and emission rates are illustrated in Figure 5.2.1. The annual geometric means and standard deviations of odour and gas concentrations were also summarized in Table 5.2.1. Due to the interaction of the type of room with the measurement month, Table 5.2.2 gives the statistical analysis results for comparison of the three rooms in each sampling months separately.



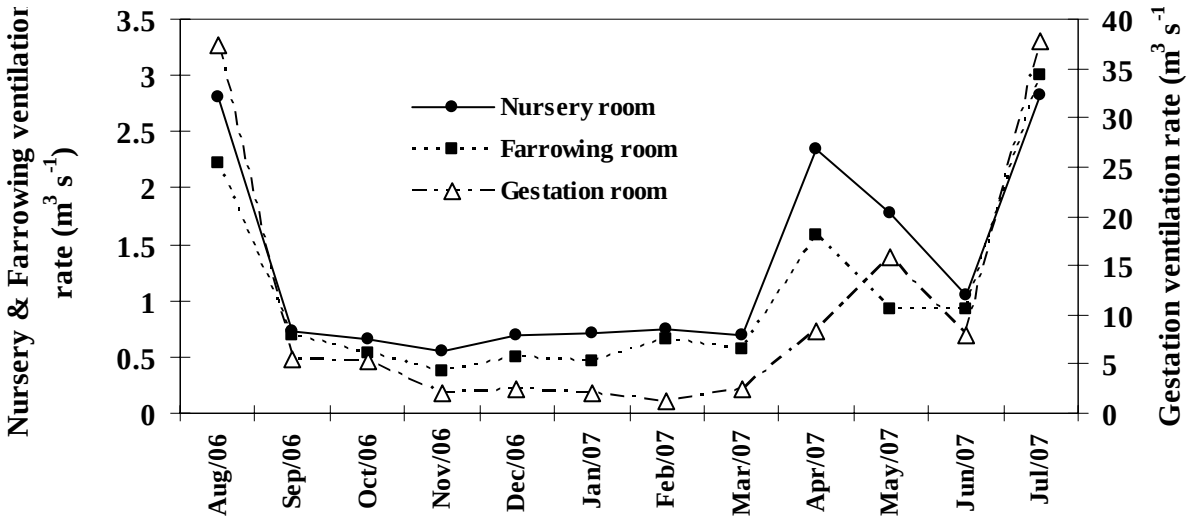
(a) Odour concentrations



(b) Odour emission rates



(c) Average room and ambient temperatures



(d) Average ventilation rates

Figure 5.2.1 Seasonal variations of odour concentration and emission

Every point in the figures of odour concentrations and emissions was the geometric mean of 2 data. Odour concentrations and emissions in October were missing because of sample shipment delay caused by adverse weather (the bus service from Saskatoon to Edmonton was cancelled for 3 days after the first day of sampling). The annual geometric means of odour concentrations for the nursery, farrowing and gestation rooms were 3255, 1990 and 1540 OU m^{-3} with corresponding odour emission rates 34.0, 16.1, and 10.2 OU m^{-2} s^{-1}, respectively. If the odour emission rates were expressed in terms of animal unit basis, the annual geomantic mean of odour emission rates were 451.8, 259.1, and 58.9 OU AU^{-1} s^{-1} respectively. Odour concentrations and emissions from the nursery room were significantly higher than the other two rooms (P<0.05). The main reason lied on its distinct diet and higher room temperature as well as frequent movement which caused high odour production. Figure 5.2.1 shows the fluctuation of the room temperature and ambient temperature throughout the year. During the measurement periods, the outside temperature varied from -8.4^{o}C in November to 32.2 ^{o}C in July, while the room temperature did not varied as much. The ventilation rate followed the similar pattern as the ambient temperature, which was high in the period between April and August and low between September and March.

As discussed previously, high outdoor temperature will result in higher ventilation rate and low odour and gas concentrations. Statistical analysis revealed that the "seasonal" factor had significant effect on odour concentrations for all three rooms (Table 5.2.2, $P<0.05$). The peak concentrations occurred in winter, in December for the nursery room, in January for the farrowing room and in February for the gestation room. The lowest odour concentrations occurred in July for all the rooms under hot weather condition. Odour emission rates of the nursery room varied from 16.9 to 89.6 OU m^{-2} s^{-1}, the farrowing room from 3.1 to 45.5 OU m^{-2} s^{-1}, and 2.4 to 63.9 OU m^{-2} s^{-1} for the gestation room. Measured emission rates in this study were comparable with results reported by Guo et al. (2006) and Zhang et al. (2007). For example, Guo et al. (2006) measured odour emission rates from two gestation, two farrowing, four nursery, and three finishing rooms throughout one year. The odour emission rate in nursery varied from 9.2 to 92.5 OU m^{-2} s^{-1} with geometric mean of 30.8 OU m^{-2} s^{-1}, while the geometric mean for gestation and farrowing room were 10.4 and 25.2 OU m^{-2} s^{-1}, respectively. It was appropriate to compare the results with experiments conducted under typical Canadian Prairie climate rather than other areas because distinctive differences of climate, building systems, and manure management exist between various areas.

As statistical analysis showed, significant seasonal difference of odour emissions were found for the nursery and gestation rooms ($P<0.05$), but not for the farrowing room ($P>0.05$). The Duncan multiple comparison given in Table 5.2.2 also indicated large difference of odour emission rates over the annual course. The Figure 5.2.1 depicts the annual variation of odour emissions which did not show obvious seasonal pattern as odour concentrations did. The odour emissions kept relatively stable for the farrowing room comparing with the nursery and gestation rooms. The large standard deviations of odour concentrations and emissions summarized in Table 5.2.1 reflected high variations of odour concentrations and emissions throughout the year for all three rooms. Odour emission peaked in August for the farrowing and gestation rooms when the ventilation rate reached the maximum level and played a dominant role in emission determination. However, the peak of odour emission from the nursery room occurred in April although its corresponding concentration and ventilation rate were not at their maximums. This

proved again that the emission rate was determined by both the concentration and ventilation rate. Since large seasonal variations in odour concentrations and emission rates were found in all the rooms, these results effectively manifested that randomly measured of odour emissions for odour dispersion modeling or setback modeling may contribute to great uncertainty.

Table 5.2.1 Comparison of the rooms for annual mean of odour concentrations and emission rate

			Odour concentration (OU m^{-3})				Odour emission rate(OU m^{-2} s^{-1})			
Room	Room t (^oC)	Animal No.	Geometric mean	Std.Dev	Max	Min	Geometric mean	Std.Dev	Max	Min
Nursery	26	230	3255	2890	8934	927	34.0	22.6	89.6	16.9
Farrowing	24	14	1990	1685	4871	362	16.1	11	45.5	3.1
Gestation	21	341	1540	1364	4096	400	10.2	18.4	63.9	2.4

Note: The number of data for geometric mean n=22 for nursery, farrowing;
n= 20 for gestation room

Table 5.2.2 Monthly variation of odour concentrations and emissions of the three rooms

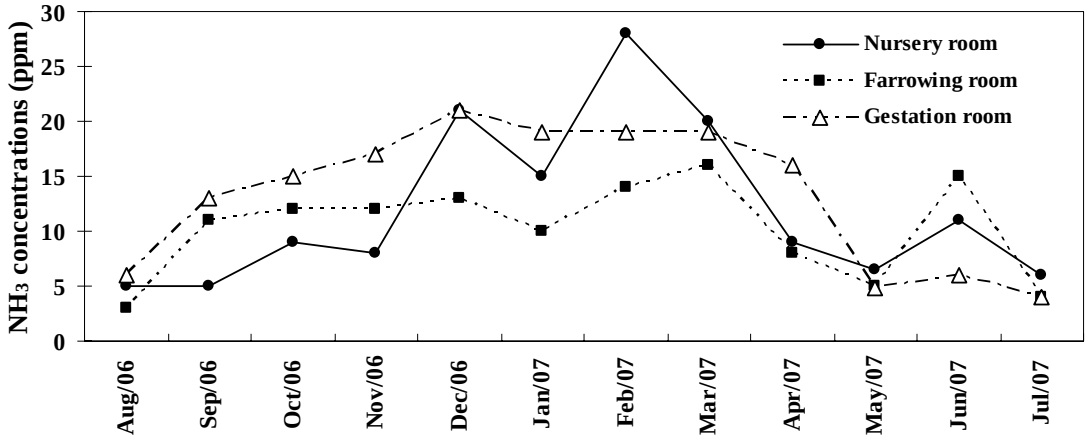
Date	Amibent t (^oC)	Odour concentration (OU m^{-3})			Odour emission rate (OU m^{-2} s^{-1})		
		Nursery	Farrowing	Gestation	Nursery	Farrowing	Gestation
Aug.2006	26.1	1448 ab	2195 bcd	1448 a	37.9 a	45.5 c	63.9 b
Sep.2006	9.8	4466 de	4095 e	2048 b	30.1 a	26.4 bc	13.2 a
Nov.2006	-8.4	3755 bcde	3444 cde	1024 a	19.3 a	12.2 abc	2.4 a
Dec.2006	-8	8934 f	3756 de	2896 c	57.6 ab	17.6 abc	8.1 a
Jan.2007	-4.5	8192 f	4871 e	3756 d	54.4 ab	20.9 abc	9.4 a
Feb.2007	-6.4	6889 e	2435 bcd	4096 d	47.6 ab	15 ab	5.8 a
Mar.2007	-0.6	4467 cde	4096 e	2233 bc	29.2 a	21.8 abc	6.7 a
Apr.2007	14.9	4096 abcd	1024 ab	1218 a	89.6 b	15.1 abc	11.9 a
May.2007	20	1024 a	362 a	512 a	16.9 a	3.1 a	9.6 a
Jun.2007	13.2	2048 abc	1722 abc		19.9 a	15 abc	
Jul.2007	32.2	927 a	538 a	400 a	24.4 a	15.1 abc	17.8 a

The means of odour concentrations or odor emission rates in the same column followed by the same letter are not significantly different (P>0.05).

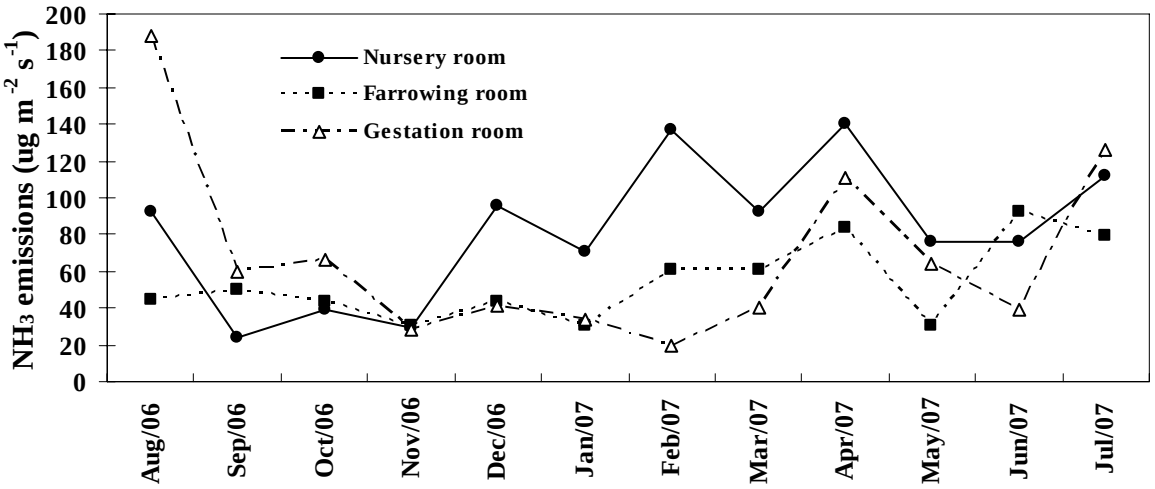
5.2.2 Seasonal NH_3, H_2S concentration and emission profiles

Figure 5.2.2 shows annual variation of NH_3 concentration and emissions throughout the year. Similar to odour concentration, the NH_3 concentration exhibited a distinct seasonal pattern with high levels (>15 ppm) during the cold seasons and low levels (<10 ppm) during the warm seasons. This fluctuation pattern was opposite of the ventilation rate variation patterns. There was a spike of NH_3 concentration in June in the farrowing

room which was probably related to the decrease of ambient temperature. The NH_3 emission rate showed less variation than NH_3 concentration and no definite variation pattern was observed. The peak emission occurred in April for the nursery, in June for the farrowing, and in August for the gestation room. The maximum NH_3 emission happened in hot season was mainly due to fairly high ventilation rate in farrowing and gestation room. For nursery room, the peak occurred in April because of its dramatic change of weather causing the sudden increase of ventilation rate.



(a) NH_3 concentrations



(b) NH_3 emission rates

Figure 5.2.2 Seasonal variations of NH_3 concentrations and emission rates

The statistical analysis results presented in Table 5.2.3 give the mean NH_3 concentrations and emissions over the 12-month monitoring period. Each data point in the figure was derived from averaging 12 data of every 3 hours. In the mean time, the

NH_3 emissions expressed on basis of animal unit were also outlined in the table. The mean NH_3 concentrations were 12, 10, and 13 ppm for the nursery, farrowing and gestation rooms, respectively, with mean NH_3 emission rates 82.2, 54.2 and 68.2 μg m^{-2} s^{-1}, respectively. Duncan's multiple comparisons presented in Table 5.2.4 indicates that NH_3 concentrations and emissions differed significantly from month to month (P<0.05).

Table 5.2.3 Annual means of gas concentrations and emissions for the three rooms

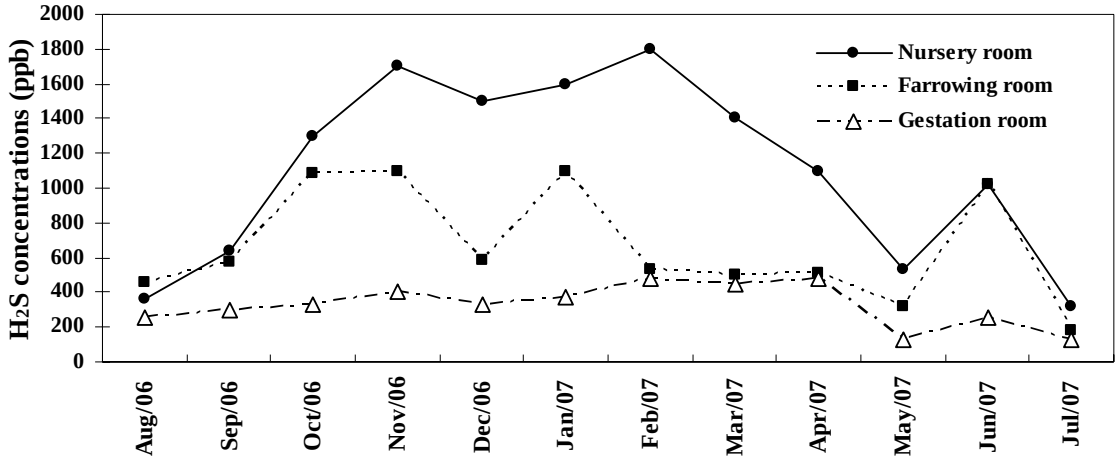
Variable	Nursery				Farrwoing				Gestation			
	Mean	S.D	Max	Min	Mean	S.D	Max	Min	Mean	S.D	Max	Min
NH_3 concentration (ppm)	12	7	28	5	10	4	16	4	13	6	21	4
NH_3 emissions (ug m^{-2} s^{-1})	82.2	38.1	139.7	23.9	54.2	22	92.6	30	68.2	50	126	19
NH_3 emissions (ug AU^{-1} s^{-1})	1010	269	1484	604	871	364	1549	467	414	333	1230	101
H_2S concentrations (ppb)	1106	529	1800	320	663	325	1100	180	327	119	480	130
H_2S emissions (ug m^{-2} s^{-1})	15.4	7.1	36.1	6.4	7.5	3.6	13.2	4	4.4	4.6	8.7	1
H_2S emissions (ug AU^{-1} s^{-1})	212	95.5	433	92.3	121	58	236	61	27.3	30	110	5.4
CO_2 concentrations (ppm)	2087	980	3596	891	1716	677	2646	704	2016	953	3578	795
CO_2 emissions (mg m^{-2} s^{-1})	22.4	8.8	37.3	13.8	12.7	4	18.5	5.4	13.6	5	23.6	6.2
CO_2 emissions (mg AU^{-1} s^{-1})	323	172	678.7	122	203	58	283	83	80.2	33	149	33
CH_4 concentrations (ppm)	114	74.7	270.2	19.2	96	48	141	16	41.3	32	70.8	11
CH_4 emissions (mg m^{-2} s^{-1})	0.78	0.78	1.2	0.2	0.56	0.7	0.69	0.2	0.42	1	0.3	0.1
CH_4 emissions (mg AU^{-1} s^{-1})	10.2	9.5	37.9	2.4	9	11	42.9	3.1	2.7	6.8	24.1	0.3
N_20 concentration (ppm)	0.39	0.04	0.45	0.31	0.5	0.2	0.97	0.3	0.42	0.1	0.53	0.3

[a] S.D means standard deviation

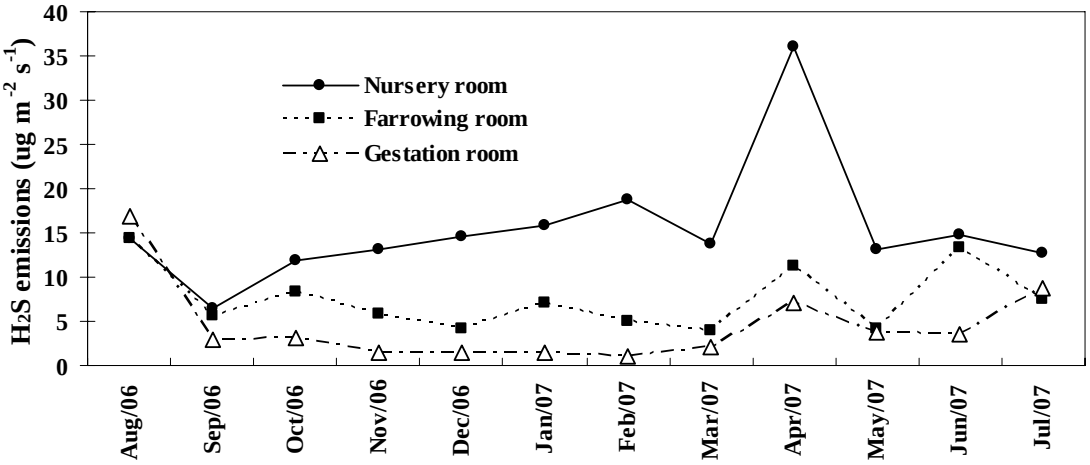
Table 5.2.4 Monthly variation of NH_3 concentrations and emissions of three rooms

Date	Amibent	NH_3 concentration (ppm)			NH_3 emission rate (ug m^{-2} s^{-1})		
	t (^oC)	Nursery	Farrowing	Gestation	Nursery	Farrowing	Gestation
Aug.2006	26.1	5 a	3 a	6 a	92.9 b	44.2 a	188 d
Sep.2006	9.8	5 a	11 c	13 b	23.9 a	50.4 ab	59.5 ab
Oct.2006	4.4	9 bc	12 cd	15 bc	38.8 a	43 a	66.6 ab
Nov.2006	-8.4	8 abc	12 cd	17 c	29.2 a	30.3 a	28.6 a
Dec.2006	-8	21 e	13 cd	21 d	96.1 b	43.1 a	41.7 ab
Jan.2007	-4.5	15 d	10 bc	19 d	70.7 b	30.5 a	33.9 a
Feb.2007	-6.4	28 e	14 de	19 d	137.5 c	61.3 abc	19.1 a
Mar.2007	-0.6	20 d	16 e	19 d	92.9 b	60.5 abc	40.3 ab
Apr.2007	14.9	9 bc	8 b	16 bc	139.7 c	83.9 cde	110.9c
May.2007	20	6.5 ab	5 a	4.8 a	76.3 b	30.9 a	64 ab
Jun.2007	13.2	11 c	15 de	6 a	75.9 b	92.6 e	39.5 a
Jul.2007	32.2	6 a	4 a	4 a	112.3 c	79.6 bcd	126.4c

The means of NH_3 concentrations or NH_3 emission rates in the same column followed by the same letter are not significantly different (P>0.05).
n=12 for each mean value



(a) H_2S concentrations



(b) H_2S emission rates

Figure 5.2.3 Seasonal variations of H_2S concentrations and emissions

Figure 5.2.3 shows seasonal variation of H_2S concentrations and emissions over one year period. H_2S concentrations in the nursery room were significantly higher than those in the farrowing and gestation rooms (P<0.05). Only H_2S concentration in the nursery room nicely followed the inverse fluctuation pattern of ambient temperature, while the H_2S concentration in the gestation room maintained a relatively steady level and changed within a small range. Drastic reduction of the ventilation rate happened in September and kept paralleled until March (Figure 5.2.1). During these months, there were still large variations of H_2S concentration, similar to the NH_3 concentration

variations. This implied that the ventilation rate was not the only reason to explain the fluctuation of concentration; other factors such as room temperature, pig activity, cleanliness, and manure management could also be important factors for these concentration variations. Although the worker's activity was recorded from 09:00 to 12:00 h on every testing day, no special situation was observed because the task routines for the stockman in each room were almost the same. Generally speaking, the H_2S emissions from these three rooms showed relatively stable levels throughout the whole year comparing with NH_3 emissions except some spikes occurred in April as affected by the fluctuation of the ventilation rate. The abrupt increase of H_2S emission in April was partly attributed to the change of ambient temperature resulted in sudden increase of ventilation rates.

Annual means of H_2S concentrations and emission rates in three different rooms were presented in Table 5.2.3. Significant effect of the room type on H_2S concentration and emission were observed (P<0.05). H_2S concentration and emission for the nursery room were significantly higher than those of the farrowing room, while the gestation room had the lowest values. H_2S concentration and emission rate of nursery varied within the range of 320 to 1800 ppb and 6.4 to 36.1 μg m^{-2} s^{-1}, respectively, while the farrowing room varied from 180 to 1100 ppb for concentration and from 4 to 13.2 μg m^{-2} s^{-1} for emission rate. In gestation room, the H_2S concentration varied from 130 to 480 ppb and emission rate changed from 1 to 8.7 μg m^{-2} s^{-1}. These results obtained in this project were agreeable with results reported by Zhu et al (2000). In his study, the H_2S emission rate from nursery ranged from 19.8 to 144, 3.09 to 7.86 from farrowing room, and 0.8 to 9.1 μg m^{-2} s^{-1} from gestation, respectively. Table 5.2.5 listed statistical comparison of mean H_2S concentrations and emissions in different room throughout the year. H_2S concentrations and emissions of all three rooms were significantly different in the annual course (P<0.05).

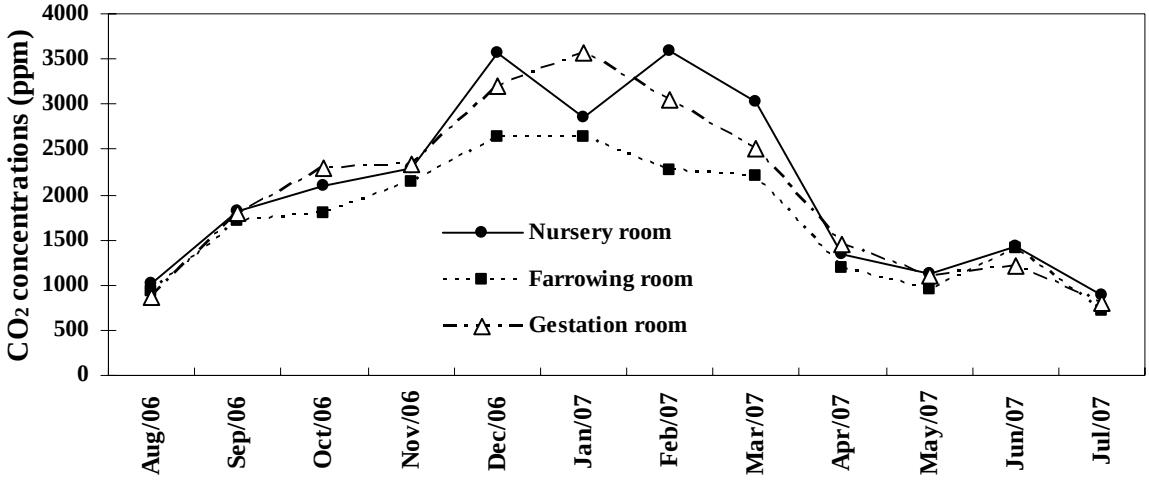
Table 5.2.5 Monthly variation of H_2S concentrations and emissions of three rooms

Date	Amibent	H_2S concentration (ppb)			H_2S emission rate (ug m^{-2} s^{-1})		
	t (^{0}C)	Nursery	Farrowing	Gestation	Nursery	Farrowing	Gestation
Aug.2006	26.1	365 a	460 ab	255 b	14.3 abc	14.3 e	16.9 d
Sep.2006	9.8	633 a	573 b	303 c	6.4 a	5.5 ab	2.9 a
Oct.2006	4.4	1300 bc	1089 c	335 cd	11.8 ab	8.2 bcd	3.1 ab
Nov.2006	-8.4	1700 ef	1100 c	400 de	13.1 ab	5.9 ab	1.4 a
Dec.2006	-8	1497 de	580 b	326 c	14.5 abc	4.1 a	1.4 a
Jan.2007	-4.5	1600 ef	1100 c	370 d	15.9 bc	7.1 abc	1.4 a
Feb.2007	-6.4	1800 f	530 b	480 e	18.7c	4.9 a	1 a
Mar.2007	-0.6	1400 cd	500 ab	450 e	13.7 ab	4 a	2 a
Apr.2007	14.9	1100 bc	510 ab	480 e	36.1 d	11.3 ce	7 b
May.2007	20	533 a	323 a	130 a	13.2 ab	4.2 a	3.7 ab
Jun.2007	13.2	1020 b	1016 c	260 b	14.9 bc	13.2 de	3.6 ab
Jul.2007	32.2	320 a	180 a	130 a	12.7 ab	7.6 bcd	8.7 c

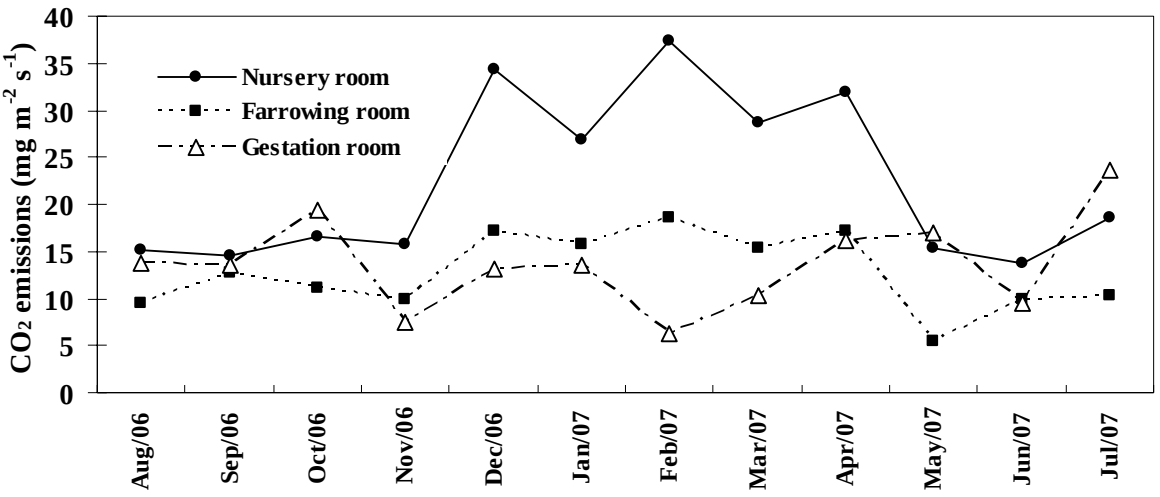
The means of H_2S concentrations or H_2S emission rates in the same column followed by the same letter are not significantly different (P>0.05).
n=12 in Aug, Sep, Oct, Nov, Dec, Jan for each mean value, n=1 in Feb, Mar, Apr
n=3 in May, Jun, July for each mean value

5.2.3 Greenhouse gas concentration and emission profiles

Greenhouse gas was considered as major contribution to global warming which attracted increasing concerns all over the world. Greenhouse gas includes CO_2, CH_4, and N_2O were also monitored for an entire year to quantify their contribution to greenhouse gas emission.



(a) CO_2 concentrations



(b) CO2 emission rates

Figure 5.2.4 Seasonal variation of CO_2 concentrations and emissions

Figure 5.2.4 exhibits the seasonal variation of CO_2 concentration that had a clear fluctuation trend with high concentration from December to March and low concentration from May to August for all three rooms. The CO_2 concentrations ranged from 891 to 3596 ppm for the nursery room, 704 to 2646 ppm for the farrowing room, and from 795 to 3578 for the gestation room (Table 5.2.3). As for CO_2 emission rates, small variations were observed in farrowing and gestation rooms, however, the CO_2 emissions from the nursery room had two apparent different levels, the high level from December to April, and the low level from May to November. Although during the period from December to April, the ventilation rates were low, the emission rates were still higher than the other months because of dominant role played by CO_2 concentration. Once again, combined effect of the ventilation rate and the concentration determined the emission rate. Table 5.2.6 provides the monthly comparison of CO_2 concentrations and emissions which delivered the information that significant variation existed among sampling months.

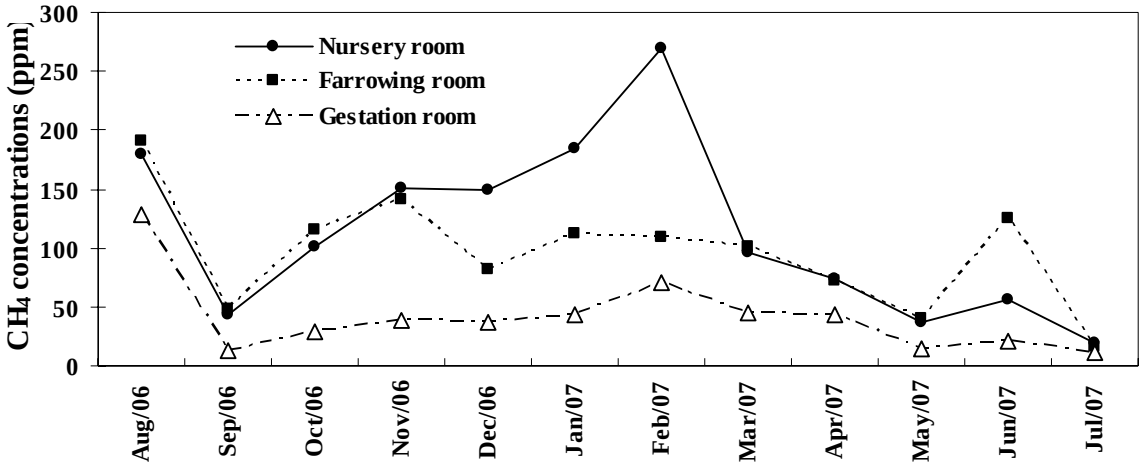
Table 5.2.6 Monthly variation of CO_2 concentrations and emissions of the three rooms

Date	Amibent t (^{0}C)	CO_2 concentration (ppm)			CO_2 emission rate (mg m^{-2} s^{-1})		
		Nursery	Farrowing	Gestation	Nursery	Farrowing	Gestation
Aug.2006	26.1	1010 ab	940 ab	860 a	15.2 a	9.4 ab	13.7 ab
Sep.2006	9.8	1819 cd	1718 de	1786 cd	14.5 a	12.7 bc	13.5 ab
Oct.2006	4.4	2090 d	1800 e	2300 de	16.5 a	11.1 ab	19.4 bc
Nov.2006	-8.4	2284 d	2143 e	2329 de	15.8 a	10.0 ab	7.5 a
Dec.2006	-8	3572 e	2638 f	3209 f	34.4 b	17.1cd	13.1 ab
Jan.2007	-4.5	2857 e	2646 f	3578 f	27 b	15.8 bc	13.5 ab
Feb.2007	-6.4	3596 e	2266 e	3038 f	37.3 b	18.5 d	6.2 a
Mar.2007	-0.6	3020 e	2201 e	2518 e	28.6 b	15.4 bc	10.4 ab
Apr.2007	14.9	1345 bc	1182 bc	1458 bc	31.9 b	17.2 cd	16.2 bc
May.2007	20	1119 ab	945 ab	1100 ab	15.5 a	5.4 a	16.9 bc
Jun.2007	13.2	1437 bc	1410 cd	1221.6 abc	13.8 a	9.8 ab	9.5 ab
Jul.2007	32.2	891 a	704 a	795 a	18.5 a	10.3 ab	23.6 c

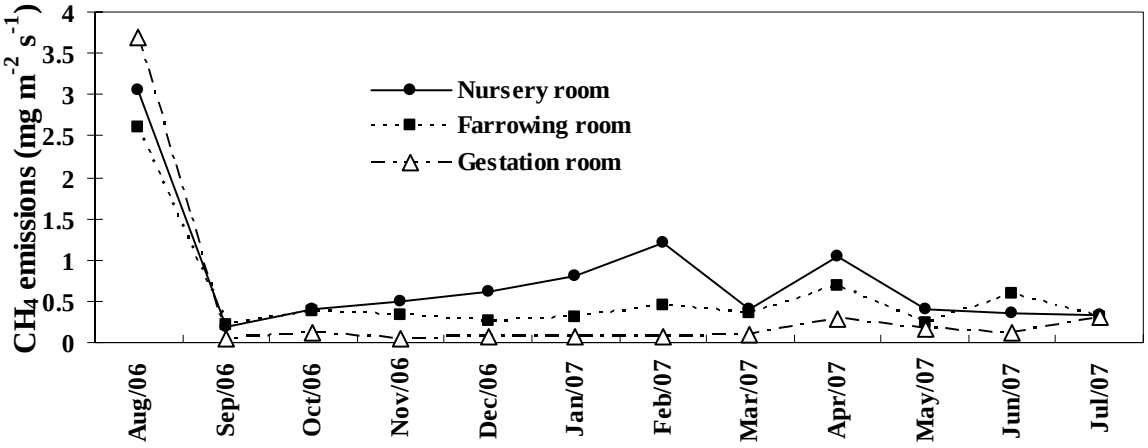
The means of CO_2 concentrations or CO_2 emission rates in the same column followed by the same letter are not significantly different (P>0.05).

n=12 in Aug, Sep, Oct, Nov, Apr, May, Jun, Jul for each mean value; n=2 in Dec, Jan, Feb, Mar

Figure 5.2.5 depicts seasonal variations of CH_4 concentrations and emission rates from the three rooms throughout the year. The annual mean CH_4 concentrations from the nursery, farrowing and gestation rooms were 113.0, 96.0, and 41.3 ppm, respectively. There were significant difference of CH_4 concentrations between the nursery and gestation rooms, and between the farrowing and gestation rooms as well (P<0.05), but no significant difference between the nursery and farrowing rooms (P>0.05).



(a) CH_4 concentrations



(b) CH_4 emission rates

Figure 5.2.5 Seasonal variations of CH_4 concentrations and emissions

Large standard deviations were observed which reflected large variability of CH_4 concentration, however, no specific variation trend was detected and it was difficult to explain the drastic low concentration in September for all the three rooms. The concentration measured in this study from the farrowing room was comparable to the CH_4 concentration range from 2.8 to 99.8 ppm reported by Laguë et al. (2003). Mean CH_4 emission rate from the nursery room was 0.77 mg m^{-2} s^{-1}, whereas 0.55 and 0.40 mg m^{-2} s^{-1} for the farrowing and gestation rooms, respectively. No significant difference among the three rooms was found if compared in unit of per square meter per second, but CH_4 emission from the nursery room was significantly higher than those of the farrowing and gestation rooms in term of per animal unit per second (P<0.05). As shown in Figure 5.2.5, CH_4 emission rates in August were significantly higher than those in the other months for all three rooms (P<0.05) because of the combined effect of high concentration and ventilation rate. In the other months the CH_4 emission rates were at lower level and varied little. The distinct drop of emission in September was caused by both large reduction of concentration and ventilation rate. Although the ventilation rates in July was close to those in August, the CH_4 emission rates of three rooms were much lower because of low CH_4 concentrations measured in July. The CH_4 emission rates obtained from this study was higher than the study conducted by Zhang et al. (2007) in Manitoba. One possible reason might be the different methods for ventilation

rate calculation. The ventilation rate of swine barn in their study was determined by measuring at five points across the radius of each running fan with a hot wire anemometer.

N_2O concentrations were measured near the exhaust fans for all three rooms in one year. The N_2O maintained at low level with mean concentration of 0.39±0.04, 0.5 ±0.18, and 0.42±0.06 ppm, respectively for the nursery, farrowing and gestation rooms. The small deviation implied that the N_2O concentrations were consistently steady through the year. As a result, the N_2O emissions were low and could be considered negligible. This conclusion was in agreement with the other studies (Zhang et al., 2007; Laguë et al., 2004)

Table 5.2.7 Monthly variation of CH_4 concentrations and emissions of three room

Date	Amibent t (^oC)	CH_4 concentration (ppm)			CH_4 emission rate (mg m^{-2} s^{-1})		
		Nursery	Farrowing	Gestation	Nursery	Farrowing	Gestation
Aug.2006	26.1	179.2 ef	190.72 g	128.7 g	3.00 c	2.60 b	3.69 e
Sep.2006	9.8	43.5 ab	47.8 bc	13.6 a	0.22 a	0.20 a	0.06 a
Oct.2006	4.4	100.8 d	116.3 ef	29.6 c	0.40 ab	0.39 a	0.12 ab
Nov.2006	-8.4	150.4 e	141 f	38.3 d	0.50 ab	0.33 a	0.06 a
Dec.2006	-8	149.3 e	81.5 cd	37.6 d	0.63 ab	0.25 a	0.07 a
Jan.2007	-4.5	184.2 f	111.9 ef	42.7 de	0.79 ab	0.32 a	0.07 a
Feb.2007	-6.4	270.2 g	108.6 e	70.8 f	1.21 b	0.44 a	0.07 a
Mar.2007	-0.6	96.6 d	100.5 de	45 e	0.41 ab	0.40 a	0.09 ab
Apr.2007	14.9	73.9 cd	71.5 cd	43 de	1.05 ab	0.69 a	0.27 d
May.2007	20	37.66 ab	39.9 ab	14 a	0.40 ab	0.22 a	0.17 c
Jun.2007	13.2	56.6 bc	125.31 ef	21.37 b	0.36 ab	0.59 a	0.13 b
Jul.2007	32.2	19.22 a	16.4 a	10.5 a	0.33 a	0.30 a	0.30 d

The means of CH_4 concentrations or CH_4 emission rates in the same column followed by the same letter are not significantly different (P>0.05).
n=2 for each mean value

Table 5.2.8 gives the annual greenhouse gas emission in terms of CO_2 equivalent basis from all rooms in the gestation, nursery and farrowing area assuming that all the 8 nursery rooms had the same emission rate as the experiment nursery room and all the farrowing rooms had the same emission rate as the experiment farrowing room, and the emissions of the group housing gestation room was calculated using the emission rate per pig place of the experiment gestation room. The total greenhouse gas emission from all the rooms was 2956 CO_2 equivalent tons per year. Comparing the contribution of

greenhouse gas emission of the three types of rooms, the gestation room accounted for 39.3 % of the total greenhouse emission because of its high pig density. The nursery and farrowing rooms contributed 37.2% and 23.5%, respectively to the total greenhouse gas emission. From the table 5.2.8, CO_2 relative contribution to the total greenhouse was 53.4%, higher than CH_4-CO_2 equivalent value of 43.9%. Since the N_2O-CO_2 equivalent contribution was only 2.7%, it could be considered negligible as compared with CO_2 and CH_4, which consistent with the results obtained in other studies (Zhang et al., 2007; Laguë et al., 2004).

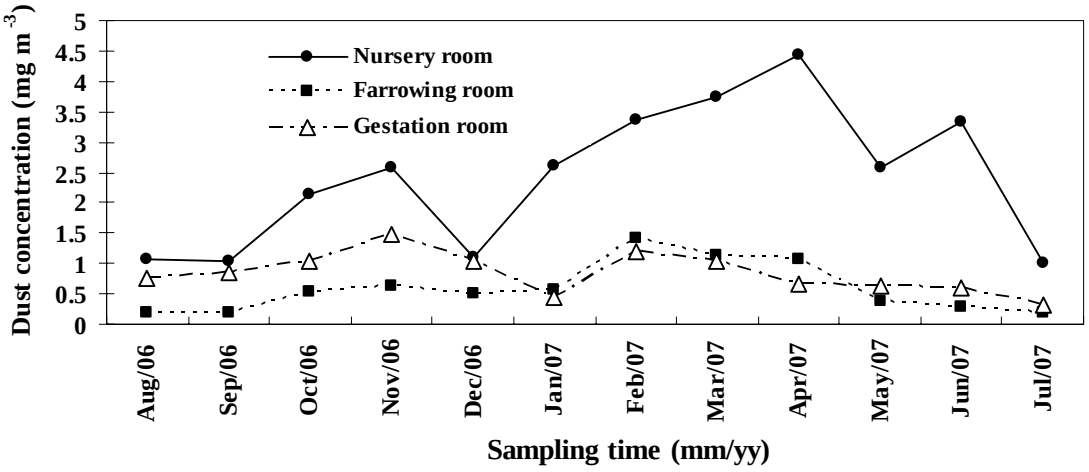
Table 5.2.8 Annual greenhouse gas emission from the three types of rooms

Variables	Nursery	Farrowing	Gestation	Total	Gas Contribution
CO_2 mean annual emission (mg $s^{-1}pig^{-1}$)	10.42	91.31	33.93	1579.9	53.4%
CO_2-CO_2 equivalent emission (ton $year^{-1}$)	604.63	322.51	652.71		
CH_4 mean annual emission (mg $s^{-1}pig^{-1}$)	0.36	4.27	1.06	1296.3	43.9%
CH_4-CO_2 equivalent emission (ton $year^{-1}$)	480.46	346.88	469.00		
N_2O mean annual emission (ug s^{-1} pig^{-1})	0.84	23.59	7.07	79.3	2.7%
N_2O-CO_2 equivalent emission (ton $year^{-1}$)	14.43	24.66	40.26		
GHG emission-CO_2 equivalent (ton $year^{-1}$)	1099.52	694.05	1161.96		
Total GHG emission-CO_2 equivalent (ton $year^{-1}$)				2956	
Room contribution (%)	37.2%	23.5%	39.3%		

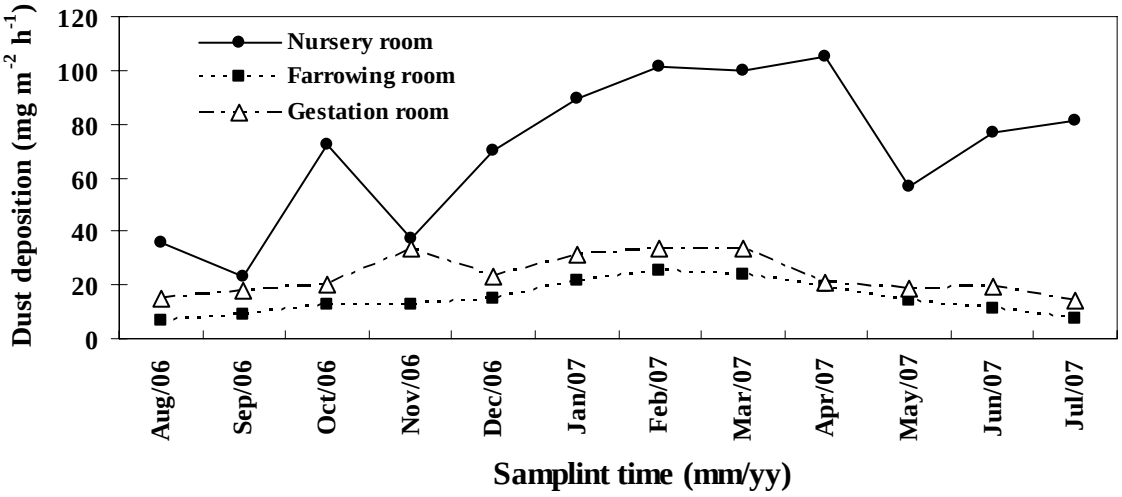
Note: According to IPCC third Assessment report (2001), the GWP (Global Warming Potential) for CH_4 is 23 and N_2O is 296.

5.2.4 Dust concentration and dust deposition

Numerous types of organic and inorganic dust are present inside swine confinement buildings. It comes from a variety of sources, including the feed, bedding materials, dried animal excrement etc, which is a primary parameter in indoor air quality (Maghirang et al., 1995). Figure 5.2.6 demonstrates seasonal variations of total dust concentration and dust deposition for the three rooms.



(a) Dust concentrations



(b) Dust depositions

Figure 5.2.6 Seasonal variations of total dust concentration and dust deposition

Generally speaking, the total dust concentration and dust deposition in cold seasons were higher than those in mild and warm seasons in all three rooms. The high level of dust in winter was closely related to the low ventilation rate which also significantly influences the spatial distribution of particle pollutants (Heber et al., 1988; Smith et al., 1993). Dust deposition was influenced by particle size, air velocity in the buildings, as well as climatic conditions.

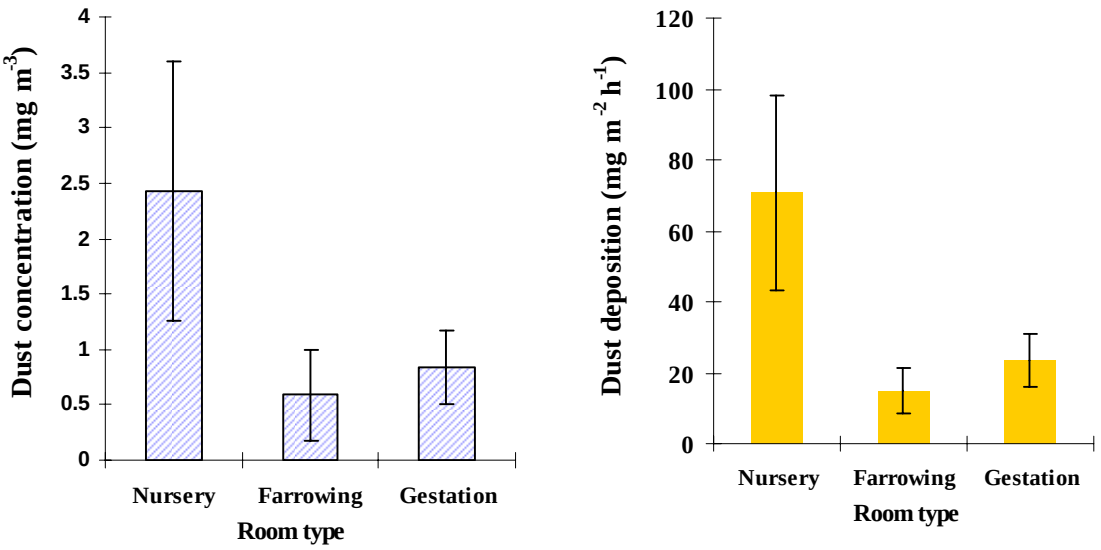


Figure 5.2.7 Annual mean of total dust concentrations and dust depositions

Figure 5.2.7 gives the annual mean of dust concentration and dust deposition. Overall mean of dust concentrations were 2.42, 0.59, and 0.84 mg m^{-3} from the nursery, farrowing and gestation room, respectively; and their corresponding annual mean dust depositions were 70.7, 14.8, and 23.3 mg m^{-2} h^{-1}. These results were within the range of the results reported by Barber, et al. (1991) and Robertson, et al. (1998). According to Occupational Health and Safety Regulations (1996) of Saskatchewan, the Permissible Exposure Limit (PEL) for total dust classified was 10.0 mg/m^3, determined as 8-hour averages, no room exceeded the threshold value. The dust level in the nursery room was significantly higher than the farrowing and gestation rooms (P<0.05), while not statistically significant different between farrowing and gestation rooms (P>0.05). It was observed during the experiment that nursery pigs in the enclosed building were more active and sensitive to the interference and their frequent movement induced the dust originated from feed, manure, and skin to be dispersed into aerial space. In another word, dust was largely re-entrained sedimented particles by agitated by animal activity.

As Figure 5.2.6 shown, the fluctuation trend of dust concentration was similar to the pattern of dust deposition for all three rooms. A good linear relationship was discovered between total dust concentration and dust deposition (Figure 5.2.8, R^2=0.76). Dust deposition would increase with the increase of dust concentration.

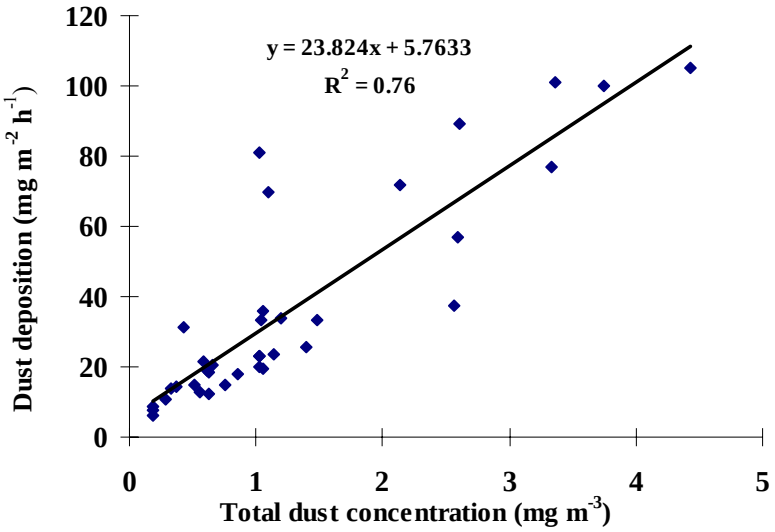


Figure 5.2.8 Relationship between dust concentration and dust deposition

Table 5.2.9 Monthly variations of dust concentration and dust deposition of three rooms

Date	Amibent t (^{o}C)	Total dust concentration (mg m^{-3})			Dust deposition (mg m^{-2} s^{-1})		
		Nursery	Farrowing	Gestation	Nursery	Farrowing	Gestation
Aug.2006	26.1	1.06 a	0.19 a	0.75 ab	35.72 ab	6.37 a	14.86 ab
Sep.2006	9.8	1.03 a	0.19 a	0.86 abc	23.31 a	8.66 a	18.07 abc
Oct.2006	4.4	2.14 ab	0.55 a	1.03 abc	72.03 abc	12.71 a	19.8 abc
Nov.2006	-8.4	2.57 abc	0.63 a	1.48 c	37.47 ab	12.37 ab	33.22 c
Dec.2006	-8	1.1 a	0.51 a	1.03 abc	69.86 abc	14.75 abc	23.18 abc
Jan.2007	-4.5	2.6 abc	0.58 a	0.43 a	89.13 c	21.34 bcd	31.2 bc
Feb.2007	-6.4	3.36 bc	1.4 b	1.2 bc	101.2 c	25.7 d	33.9 c
Mar.2007	-0.6	3.75 bc	1.14 b	1.04 abc	99.92 c	23.65 cd	33.22 c
Apr.2007	14.9	4.43 c	1.06 b	0.65 ab	105 c	19.45 bcd	20.55 abc
May.2007	20	2.59 abc	0.37 a	0.63 ab	56.7 abc	14.4 abc	18.4 abc
Jun.2007	13.2	3.34 bc	0.28 a	0.61 ab	76.9 bc	11 ab	19.02 abc
Jul.2007	32.2	1.02 a	0.18 a	0.33 a	81.2 bc	7.74 a	13.99 a

The means of total dust concentrations or dust deposition in the same column followed by the same letter are not significantly different (P>0.05).
n=2 for each mean value

Table 5.2.9 gives the Duncan multiple comparison results for the whole year for the nursery, farrowing and gestation rooms separately. Large differences among months were observed, which indicated large variation of dust condition within each room. Although the dust level in the swine building did not exceed the exposure limits set by the Saskatchewan regulations even under the worst condition in winter, it exceeded the recommended value brought by Donham (2000) who suggested the total dust is 2.4 mg

m^{-3} in swine buildings. Therefore, it is necessary for stockmen working inside the barns to take some protective measures in the long run.

Researchers pointed out that dust is a complicating factor in concentrating and transporting odours (Bottcher et al., 2004). Substantial amounts of odorous compounds and ammonia emitted from swine buildings are adsorbed and transported by dust particles (Donham et al. 1986; Parbst, 1998). However, we did not find any relationship between odour concentration and dust concentration in this study. This shows accordance with the results reported by Williams (1989) who found that there was no correlation between odour concentration and dust mass or surface area in broiler house air. The high dust concentration was not definitely related to high odour concentration because odour is a complex compound not only influenced by dust concentration, but also particle size, particle surface area, moisture content of the dust, animal activity etc.

5.2.5 Summary of seasonal measurement

Large variation of odour, gas, and dust concentration and emission were observed for all three rooms throughout one year. These results indicated that randomly-grab samples used in air dispersion modeling or setback modeling would contribute to great uncertainty. In this study, the odour concentration in nursery, farrowing, and gestation room varied from 927 to 8934, 362 to 4871, and 400 to 4096 respectively. And their corresponding geometric mean emissions were 34, 16.1, and 18.4 OU m^{-2} s^{-1}. Results obtained in this study were comparable with results reported by Guo et al. (2006) and Zhang et al. (2007), both of which were conducted on the similar region as this study on Canadian Prairies. Guo et al. (2006) measured odour emission rates from two gestation, two farrowing, four nursery, and three finishing rooms throughout one year. The odour concentration varied from 707 to 7795 OU m^{-3} for nursery, 403 to 3531 OU m^{-3} for farrowing, and 195 to 4993 OU m-3 for gestation, respectively. The odour emission rate in nursery varied from 9.2 to 92.5 OU m^{-2} s^{-1} with geometric mean of 30.8 OU m^{-2} s^{-1}, while the geometric mean for gestation and farrowing room were 10.4 and 25.2 OU m^{-2} s^{-1}, respectively. Zhang et al (2007) measured odour emissions from two swine farrowing farms from June to September. The geometric means of our emission rates

were 7.6 and 11.6 OU m^{-2} s^{-1} for the gestation barns and 22.7 and 23.0 OU m^{-2} s^{-1} for the farrowing barns, which in the same range as the results in this study. Additionally, the results were accord with the summary reported by Wood et al (2001). He concluded that odour emission rates for nursery, farrowing, and gestation ranged from 6.7 to 47.7, 3.2 to 47.7, and 4.8 to 21.3 in U.S and Netherlands. Wood also presented the results measured in Minnesota over a 3-year period. The mean and ranges of odour emissions from nursery, farrowing, and gestation barns were 8.7 (1.5 to 97.1), 4.8 (0.1 to 16.7), and 12.6 (1.2 to 192). The differences were mainly due to the difference between climate, sampling period, ventilation rate measurement, manure management etc.

Figure 5.2.9 to Figure 5.2.12 show the relationships between the odour concentration and NH_3, H_2S, CO_2 and CH_4 concentrations. The data were pooled from all three rooms in three diurnal measurements and seasonal measurements.

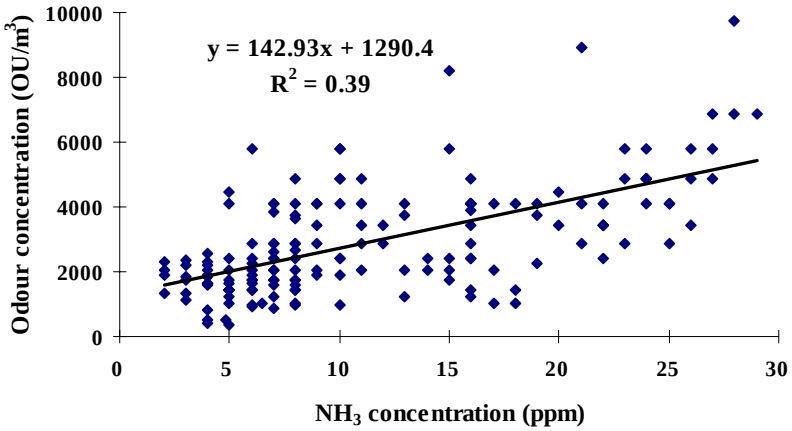


Figure 5.2.9 Relationship between odour concentrations and NH_3 concentrations

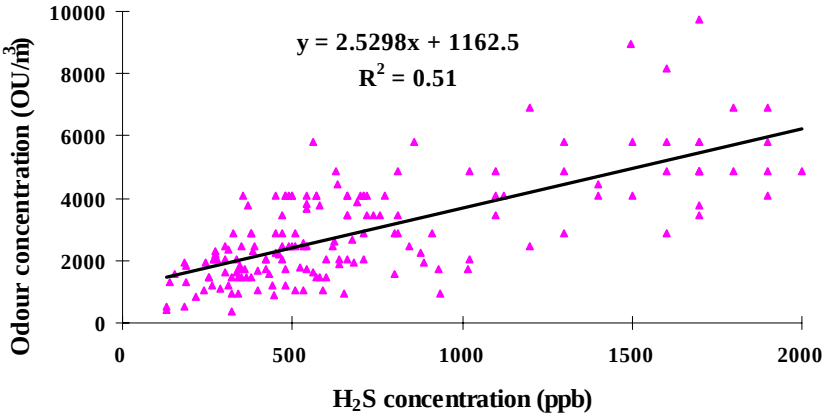


Figure 5.2.10 Relationship between odour concentrations and H_2S concentrations

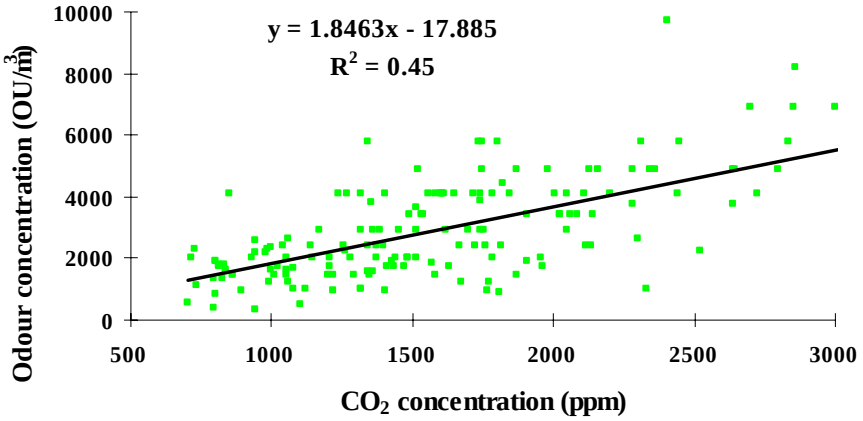


Figure 5.2.11 Relationship between odour concentrations and CO_2 concentrations

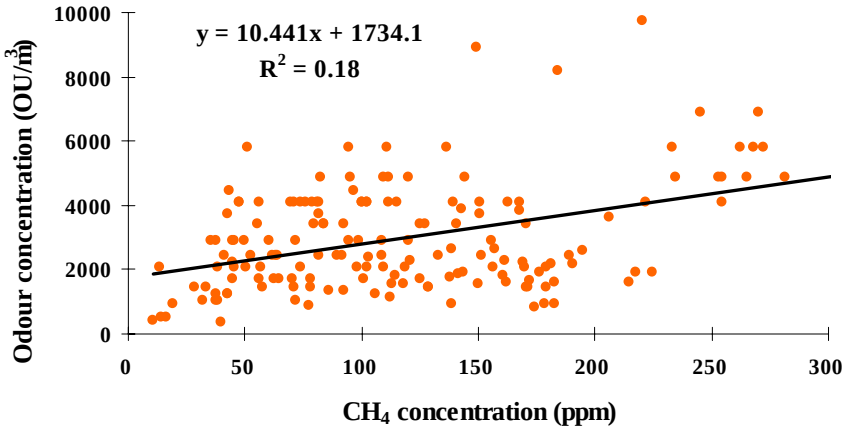


Figure 5.2.12 Relationship between odour concentrations and CH_4 concentrations

As the figures presented, this study exhibited positive correlations between odour concentrations and gas concentrations (R^2 =0.39-0.51), i.e., odour concentration would increase with increase of NH_3, H_2S, and CO_2 concentrations. There was little correlation between odour and CH_4 concentrations

The total greenhouse emission from all the nursery, farrowing, and gestation room was 2956 CO_2 equivalent tons per year. The relative contribution from nursery, farrowing, and gestation were 37.2%, 23.5%, and 39.3%, respectively. The mean CO_2 emission from farrowing and gestation were 17505 g AU^{-1} d^{-1} and 6930 g AU^{-1} d^{-1}. The results were agreeable with results reported by Zhang et al (2007). The CO_2 emission from farrowing in two farms were 16588, 11576 g AU^{-1} d^{-1}, and 11514, 4808 g AU^{-1} d^{-1} from

gestation. However, the CH_4 emissions obtained from Zhang (2007) were lower than this study, which might be attributed to different ventilation rate method and sampling period.

Table 5.2.10 outlined the maximum value that was observed in the entire study and mean NH_3, H_2S, CO_2, and total dust concentration throughout one year. Compared with Permissible Exposure Limit (PEL) established by Occupational Safety and Health Regulations (1996) in Saskatchewan, all the indoor air quality parameters below the air quality requirement except the maximum NH_3 concentration in the finishing room exceeded the PEL . However, long-term exposure to the low level of contaminants would still cause some unfavourable heath issues which were reported by various studies (Olson et al., 1996; Donham et al, 1977). According to the research reported by Dr. Kelly Donham (1995), he suggested NH_3 7 ppm, CO_2 1540 ppm, and total dust 2.4 mg m^{-3} as a goal to decrease the chance of developing disease. Therefore, effective mitigation technology should be introduced to reduce the risk of health problems.

Table 5.2.10 Summary of Indoor air quality in the swine rooms

Parameter	Measured values								PEL	
	Nursery		Farrowing		Gestation		Finishing			
	Max	Mean	Max	Mean	Max	Mean	Max	Mean	(TWA)	STEL
NH_3 (ppm)	29	12	17	10	26	13	39	20	25	35
H_2S (ppb)	2000	1106	1100	663	810	327	810	110	10ppm	15 ppm
CO_2 (ppm)	3596	2087	2646	1716	3578	2016	7045	4030	5000	35000
Total dust (mg m^{-3}	4.43	2.42	1.4	0.59	1.48	0.84	N/A	N/A	10	20

Note: TWA means 8-h Time Weighted Average

STEL means 15-minute Short Time Exposure Limit

N/A means Not Available

5.3 Summary and Comparison of the Four types of rooms

This study was only one part of the project which included extensive diurnal and seasonal measurements in finishing rooms with two fully slatted floor rooms and two partially slatted floor rooms. This section provides the brief summary of four types of rooms.

5.3.1 Summary of odour concentration and emission rates

The results obtained from all four types of rooms are presented in Table 5.3.1. Odour concentrations in cold season were much higher than those under mild or warm weather conditions due to reduced air exchange rate in all types of rooms. However, in this study, the odour concentration and emission rates from the finishing rooms were the lowest (except that their odour emission rates in winter was higher than that in the gestation room), which was not agreeable with the results in most literatures (Guo, et al., 2006; Wood et al., 2000). Possible reasons might be that the finishing rooms were measured in a different year than the other three rooms. Climate was not the same for these two years and animal conditions and management might be different. Furthermore, the odour panels at the Olfactometry Laboratory were different for these two years. The odour concentration measurement is a subjective procedure which is influenced by the olfactory sensitivity of the assessors, so different odour panel may respond differently to the same odour sample.

Diurnal variation of odour emission was observed in all four rooms in August because of significant variability of ventilation rates. However, in winter, odour emission did not vary diurnally for all the rooms. Under mild climate condition, only odour emissions from farrowing room varied diurnally. Due to diurnal variation of odour emission from production units under specific weather conditions in this project, it was recommended to take multiple sampling during the day under different weather conditions in order to reduce the uncertainty of source emission estimation.

Table 5.3.1 Three diurnal measurement results of odour concentrations and emission rates

	Nursery			Farrowing		
Variable	**Warm**	**Cold**	**Mild**	**Warm**	**Cold**	**Mild**
Odor concentration (OU m^{-3})	1971	5547	3755	1973	3252	2138
Odor emission (OU m^{-2} s^{-1})	34.9	39.3	70	29.4	14.3	30.7
Odor emission(OU AU^{-1} s^{-1})	491.3	265.3	458.6	588.7	234.5	510.2

	Gestation			Finishing		
Variable	**Warm**	**Cold**	**Mild**	**Warm**	**Cold**	**Mild**
Odor concentration (OU m^{-3})	1434	3519	1837	434	2262	1190
Odor emission (OU m^{-2} s^{-1})	35.1	6.3	14.2	18.8	15	10.0
Odor emission(OU AU^{-1} s^{-1})	289.4	38.7	102.5	124.5	105.8	81.9

Table 5.3.2 Annual means of odour concentrations and emission rates of four rooms

Room	Room t (^{o}C)	Animal unit	Odour concentration (OU m^{-3}) Geometric mean	S.D	Max	Min	Odour emission rate(OU m^{-2} s^{-1}) Geometric mean	S.D.	Max	Min
Nursery	26	9.3	3255	2890	8934	927	34.0	22.6	89.6	16.9
Farrowing	24	7	1990	1685	4871	362	16.1	11	45.5	3.1
Gestation	21	146.6	1540	1364	4096	400	10.2	18.4	63.9	2.4
Finishing 1	18.2	35.5	1145	752	2964	221	14.3	64.3	28.9	3.6
Finishing 2	18.8	37.6	1929	1175	3822	347	21.9	43.9	36	11.1

The geometric means of annual odour concentration and emission rates from four types of rooms were presented in Table 5.3.2. The results for the finishing room 1 was the average of the two rooms with partially slatted floors while the finishing room 2 represented the average of the two rooms with fully slatted floors. Large standard deviation shown in the table indicated large seasonal variations in odour concentrations and emissions were found in all the rooms. The nursery room had the highest odour concentration and emission rate. The finishing rooms with fully slatted floor had higher odour concentration and emissions than the finishing rooms with partially slatted floor because of large manure exposure area in fully slatted flooring. From statistical analysis, it was found that significant seasonal variation existed in all the four room types and influenced greatly by ambient weather conditions (P<0.05). However, no specific seasonal variation pattern was observed.

In order to estimate the total odour emission from different area of the swine barn, the total odour emission was calculated and given in Table 5.3.3. Based on the floor area of each type of room, the average total emission rate from this barn was 123,174 OU s^{-1}. The finishing area contributed 53.0% of the total emission which was considered as the major odour emission source. Meanwhile, the nursery area was the secondary odour source contributing 23.6%. the farrowing and gestation area contributed almost equally with contribution of 11.2% and 12.2%, respectively. These results provided the swine producer with the primary targeting area to reduce the odour emission with practical mitigation technology.

Table 5.3.3 Total odour emission from the barn and relative contribution of each area

Variable	Nurserry	Farrowing	Gestation	Finishing
Total emission of each area (OU s^{-1})	29104	13782	14986	65302
Total emission of the barn (OU s^{-1})		123174		
Contribution of each area (%)	23.6	11.2	12.2	53.0

The total emission based on 8 nursery rooms, 8 farrowing rooms, one installed and one group gestation room, and 14 finishing rooms.

5.3.2 Summary of gas concentrations and emission rates

Tables 5.3.4 to 5.3.6 provide a summary of annual means of NH_3, H_2S, and CO_2 concentration and emission rates on the basis of floor area and animal unit from all four types of rooms. For NH_3 concentrations and emission rates, the finishing room exhibited the highest levels on a yearly basis with mean concentration of 14 and 20 ppm for the room with partially slatted floor and the room with fully slatted floor, respectively; and their corresponding mean emission rate of 112.3 and 181.7 μg m^{-2} s^{-1}, respectively. NH_3 concentration in the farrowing room had the lowest level with mean concentration of 10 ppm and mean emission rate 54.2 μg m^{-2} s^{-1}. Large standard deviation of NH_3 concentration and emissions reflected considerably variations of NH_3 level. In general, the NH_3 concentration increased with the decrease of outside temperature because gas was accumulated within the building due to less air exchange rate. However, for the NH_3 emission, no specific variation pattern was observed because it depended on both concentrations and ventilation rates.

Table 5.3.4 Annual means of NH_3 concentrations and emissions of the four types of rooms

Room	NH_3 concentration (ppm)				NH_3 emission rate (ug m^{-2} s^{-1})				NH_3 emission rate (ug AU^{-1} s^{-1})			
	Mean	S.D.	Max	Min	Mean	S.D.	Max	Min	Mean	S.D.	Max	Min
Nursery	12	7	28	5	82.2	38.1	139.7	23.9	1009.7	269.4	1484.4	604.3
Farrowing	10	4	16	4	54.2	21.6	92.6	30.3	870.8	363.8	1549.1	466.6
Gestation	13	6	21	4	68.2	49.6	126.4	19.1	413.6	332.9	1230	101.2
Finishing 1	14	9	33	3	112.3	59	193.3	38.2	800.9	365.7	1689.8	410.9
Finishing 2	20	11	36	6	181.7	83.3	362.3	63.7	1201.4	358.8	1759.3	553.2

As for H_2S concentration, the finishing rooms were the lowest throughout the year, which was unexpected. The analyzers used were the same model and for the last few months of 2006 to 2007 measurement the same analyzer as used in the finishing rooms was used. Therefore, the uncertainty caused by the difference of the analyzers should be minimal. In the finishing room, the H_2S concentrations were consistently within a range

of 0.01-0.15 ppm during most of measurement period but with two sharp peaks (0.36 ppm and 0.47 ppm) occurred in Oct. 2004 and Mar. 2005, which could be explained by low ventilation rate in October and high pig weights in March compared to other sampling months. It should be pointed out that the H_2S concentrations in the finishing rooms were taken in a 2-3 min period at 10:00 h while the H_2S concentrations in the nursery, farrowing and gestation rooms were the average 3-h concentrations from 09:00 to 12:00 h. However, this measurement method difference should not result in the extent of difference as observed. Hence, the H_2S concentrations measured in the four rooms might represent their true values. The lower H_2S level in the finishing rooms than those in the other rooms might be mainly caused by the different measurement years, the same as the lower odour concentrations and emissions from the finishing rooms comparing with the other three rooms. H_2S concentrations and emission rates varied significantly over the year, but no certain variation pattern were observed

Table 5.3.5 Annual means of H_2S concentrations and emissions of the four types of rooms

Room	H_2S concentration (ppb)				H_2S emission rate (μg m^{-2} s^{-1})				H_2S emission rate (μg AU^{-1} s^{-1})			
	Mean	S.D.	Max	Min	Mean	S.D.	Max	Min	Mean	S.D.	Max	Min
Nursery	1106	529	1800	320	15.4	7.1	36.1	6.4	212.4	95.5	433	92.3
Farrowing	663	325	1100	180	7.5	3.6	13.2	4	121.1	58	235.7	61.1
Gestation	327	119	480	130	4.4	4.6	8.7	1	27.3	30.3	110.4	5.4
Finishing 1	78	100	365	18	2.5	3.2	9.6	0.11	17.4	24.3	82.2	1.2
Finishing 2	110	125	390	17	3	3.5	10.3	0.35	18.5	20.8	63.7	1.2

CO_2 concentration in all four rooms showed a clear seasonal trend with high levels in winter and low level in summer. Table 5.3.6 provided the results of CO_2 concentrations and emissions obtained from the rooms. The nursery room had the highest CO_2 concentration while the other three rooms had similar levels. The finishing room had the highest emission level in term of per square meter per second, followed by the nursery, gestation, and farrowing rooms. The results were different if compared on the basis of animal unit. It is vital to point out the emission units when making comparison.

Table 5.3.6 Annual mean of CO_2 concentrations and emissions of the four types of rooms

Room	CO_2 concentration (ppm)				CO_2 emission rate (mg m^{-2} s^{-1})				CO_2 emission rate (mg AU^{-1} s^{-1})			
	Mean	S.D.	Max	Min	Mean	S.D.	Max	Min	Mean	S.D.	Max	Min
Nursery	2087	980	3596	891	22.4	8.8	37.3	13.8	322.9	171.8	678.7	122.3
Farrowing	1716	677	2646	704	12.7	4	18.5	5.4	202.6	57.9	282.7	82.5
Gestation	2016	953	3578	795	13.6	5	23.6	6.2	80.2	32.7	148.7	32.9
Finishing 1	1607	1151	3847	295	31.2	11.6	45.1	9.3	221.1	69.4	370.4	147
Finishing 2	1733	1087	3387	330	35.9	11.6	50.9	15	239.6	62.5	361.1	150.5

5.3.3 Summary of the indoor air quality of four rooms

Regarding the air quality in these swine rooms, the measured values were all far below the 8-h averaged exposure limits set by Occupational Safety and Health Regulations (1996) of Saskatchewan except the maximum NH_3 value measured in the finishing room, which was 39 ppm that exceeded the STEL value of 35 ppm (Table 5.3.7). Extra attention should be paid when workers entered into finishing room.

Table 5.3.7 Indoor air quality of four types of rooms

Parameter	Measured values								PEL	
	Nursery		Farrowing		Gestation		Finishing			
	Max	Mean	Max	Mean	Max	Mean	Max	Mean	(TWA)	STEL
NH_3 (ppm)	29	12	17	10	26	13	39	20	25	35
H_2S (ppb)	2000	1106	1100	663	810	327	810	110	10ppm	15 ppm
CO_2 (ppm)	3596	2087	2646	1716	3578	2016	7045	4030	5000	35000
Total dust (mg m^{-3}	4.43	2.42	1.4	0.59	1.48	0.84	N/A	N/A	10	20

Note: TWA means 8-h Time Weighted Average

STEL means 15-minute Short Time Exposure Limit

N/A means Not Available

5.4 Modeling of Odour Concentrations and Emissions

Due to the interaction effects of types of room with the measurement month as reported in previous chapter, the modeling was analyzed separately according to different types of room. Four factors including ventilation rate, ambient temperature, room temperature, and animal unit were selected as the independent variables in the prediction models. In the statistical models, *Ti* = Room temperature, *To*= Ambient temperature, *V*= Ventilation rate, *AU*= Animal unit. The total of 56 3-h odour and methane data were used in the modeling, while for gases, 3-h data and hourly data in three diurnal measurements were used, a total of 201 data points. There were some data missing. 70% of data randomly selected from the diurnal and seasonal measurements were pooled into the model development, while the rest of 30% data were used to validate the models. In order to develop the relationship between observed variables and four predictors, multiple linear regression and secondary order polynomial regression were both tried in the SPSS linear regression procedures. However, there was little improvement in secondary order polynomial regression models and the expressions were too

complicated. According to the pre-modeling results and the study results by Sun (2005), multiple linear regression procedure was utilized for model development.

5.4.1 Modeling results for the nursery room

For model development, 70% of random data were pooled into the regression procedure of SPSS to generate a multiple linear regression models. In order to validate the fitness of the model, 30% of the rest random data were used to evaluate. Table 5.4.1 provides the SPSS output results for modeling part and validation part. In the modeling part, the R square for prediction models ranged from 0.68 for odour concentration models to 0.96 for H_2S concentration and emission models. R square closer to value 1, the better the model is. For significance testing, predictors had different significance effect on dependent variables. Consider odour concentration for example, although ventilation rate, inside temperature, and animal unit had no significant effect on odour concentration, they were still included in the model. This was because these variables still contributed to the model to some extent. In the validation part, paired t test and fractional bias (FB) test were used to evaluate the model. Only the significance of H_2S concentration less than 0.05 ($P<0.05$), which meant significant difference existed between predicted values and measured values. FB for all variables fell into the range of $-0.25< FB< 0.25$, which was the suggested limit set by ASTM (2003). The FB of CO_2 emission statistical model was -0.0007, which had highest prediction accuracy, while odour concentration had lowest level (FB=0.248). Basically, the gas models had better prediction than odour models that might because odour was a complex combination which was easily influenced by other factors, such as workers activity and dirtiness of the room.

In the following figures, X axis indicates the measured data, while Y axis denotes the predicted data. The left graph gives the comparison results for modeling data, and the right graph shows the results for validation data. More data points were close to the 45 angle line, better the model was. There were 2 outlier discarded in the validation results of odour concentration and 7 outlier in odour emission results.

Table. 5.4.1 SPSS results for modeling part and T test and FB test for validation part for nursery room

Dependent variable	Modeling Part							Validation part					
								T test					FB
	R^2	C.V	Root MSE	V	Ti	To	AU	Mean difference	S.D	T value	df	P-value	
Odour Con ($OU\,m^{-3}$)	0.68	40.9	1297.7	NS	NS	S	NS	-1045	3813.9	-1.06	14	0.31	0.248
Odour ER ($OU\,s^{-1}$)	0.75	51.1	1822.6	NS	NS	NS	S	-458.4	1948.5	-0.74	9	0.47	0.077
NH_3 Con (ppm)	0.95	64.4	2.3	S	S	S	S	-0.27	2.74	-0.78	60	0.44	0.021
NH_3 ER ($mg\,s^{-1}$)	0.78	22.8	1.5	NS	S	NS	S	-0.19	1.55	-0.97	60	0.34	0.017
H_2S Con (ppb)	0.96	65.5	119.5	NS	S	NS	S	-149.33	233.58	-3.62	31	0.001	0.159
H_2S ER ($ug\,s^{-1}$)	0.96	48.1	192.8	NS	NS	NS	S	2.08	260.22	0.045	31	0.96	-0.001
CO_2 Con (ppm)	0.87	32	221.7	S	S	NS	S	19	145.46	0.89	45	0.38	-0.012
CO_2 ER ($mg\,s^{-1}$)	0.85	29.5	395.3	S	NS	NS	NS	1.95	253.54	0.052	45	0.96	-0.0007
CH_4 Con (ppm)	0.88	45.2	32.8	NS	NS	NS	S	-15.51	40.91	-1.61	17	0.13	0.108
CH_4 ER ($mg\,s^{-1}$)	0.9	54.9	27.9	NS	NS	NS	NS	-13.74	40.83	-1.43	17	0.17	0.093

Note: Con=concentration; ER=emission rate; S= Independent variable had significant effect on dependent variable ($p<0.05$)

NS=Independent variable had no significant effect on dependent variable ($p>0.05$)

N/A= not available; C.V=coefficient of variation; Root MSE= root of mean square error

Mean difference= Measured value- predicted value

FB= fractional bias

1) Odour concentration model (*OC*: OU m^{-3})

$$OC = 59069.76 - 676V - 2493.6Ti - 600.73To - 4359.9AU + 126.63V \times Ti + 78.33V \times To - 509.55V \times AU + 216.63Ti \times AU - 35.75To \times AU$$

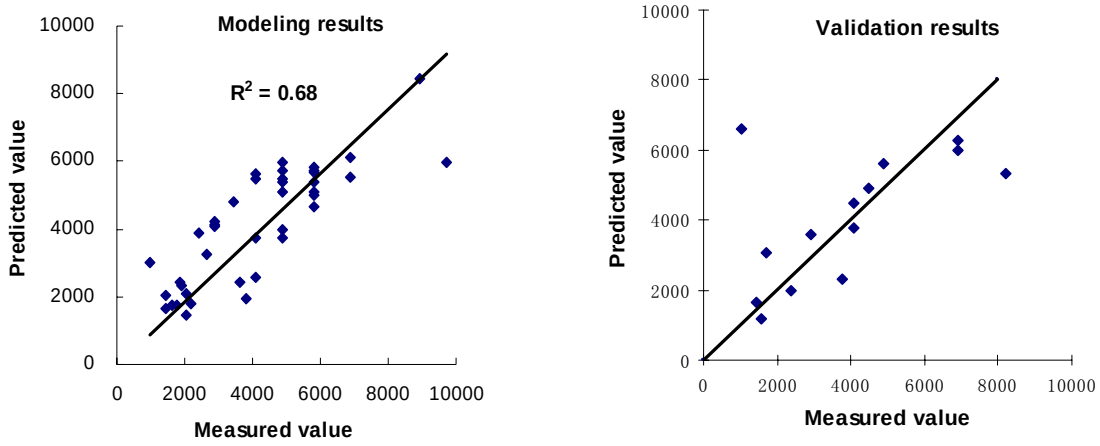


Figure 5.4.1 Modeling and validation results of odour concentration for nursery

2) Odour emission model (*OE*: OU s^{-1})

$$OE = 15400 - 14592.7V - 6815.98Ti - 54.75To - 9933.12AU + 980.7579V \times Ti - 171.57V \times To - 407.97V \times AU + 457.94Ti \times AU + 18.27To \times AU$$

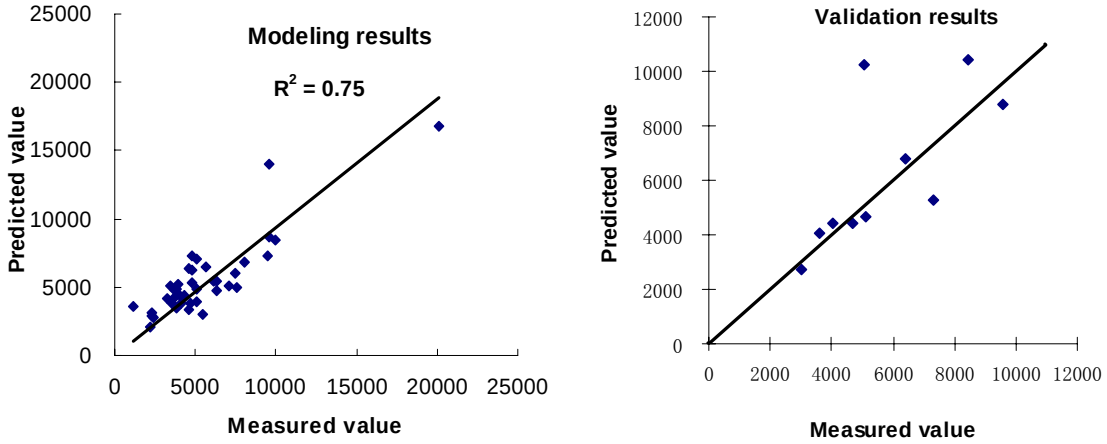


Figure 5.4.2 Modeling and validation results of odour emission for nursery

3) NH_3 concentration model (*NC*: ppm)

$$NC = 88.54 - 30.48V - 2.58Ti + 1.88To - 4.02AU + 0.4405V \times Ti + 0.6687V \times To + 0.28V \times AU - 0.009Ti \times To + 0.195Ti \times AU - 0.058To \times AU$$

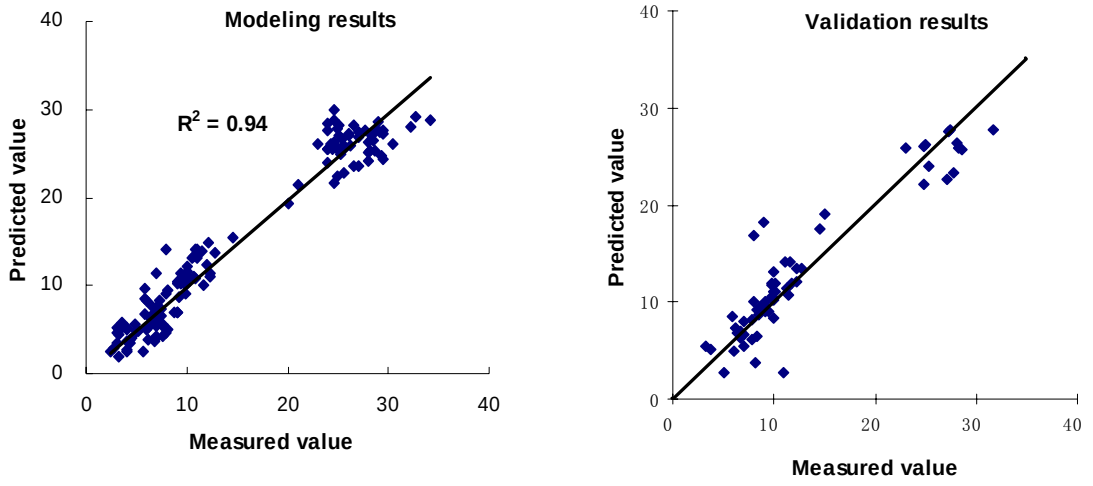


Figure 5.4.3 Modeling and validation results of NH_3 concentration for nursery

4) NH_3 emission model (NE: mg s^{-1})

$$NE = 44.6 - 7.248V - 1.572Ti + 0.65To - 2.403AU + 0.2496V \times Ti + 0.0639V \times To + 0.132V \times AU - 0.02467Ti \times To + 0.117Ti \times AU - 0.024To \times AU$$

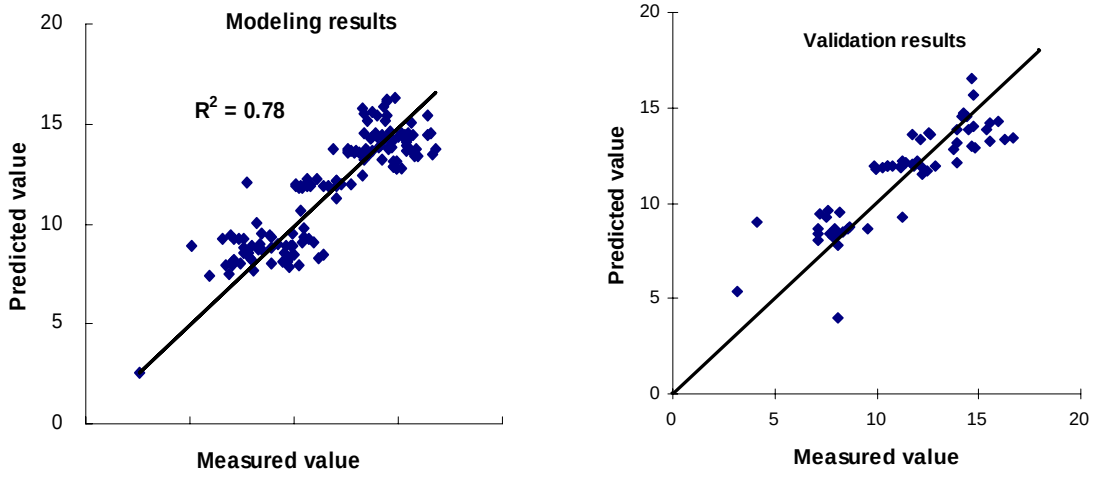


Figure 5.4.4 Modeling and validation results of NH_3 emission for nursery

5) H_2S concentration model (HC: ppb)

$$HC = -1734.7 - 494.7V + 116.01Ti - 75.0To + 500.07AU + 21.88V \times Ti + 2.38V \times To - 13.13V \times AU + 0.76Ti \times To - 20.28Ti \times AU + 4.31To \times AU$$

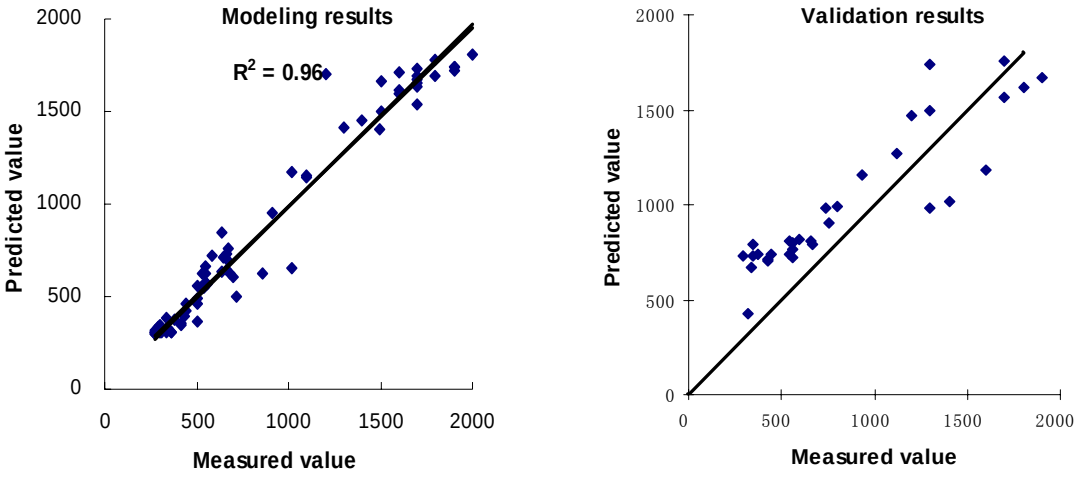


Figure 5.4.5 Modeling and validation results of H_2S concentration for nuresry

6) H_2S emission model (*HE*: mg s^{-1})

$$HE = -3042.5 - 1815.3V + 133.45Ti - 24.28To + 865.53AU + 132.74V \times Ti - 64.18V \times To + 49.5V \times AU - 0.40Ti \times To - 38.11Ti \times AU + 6.87To \times AU$$

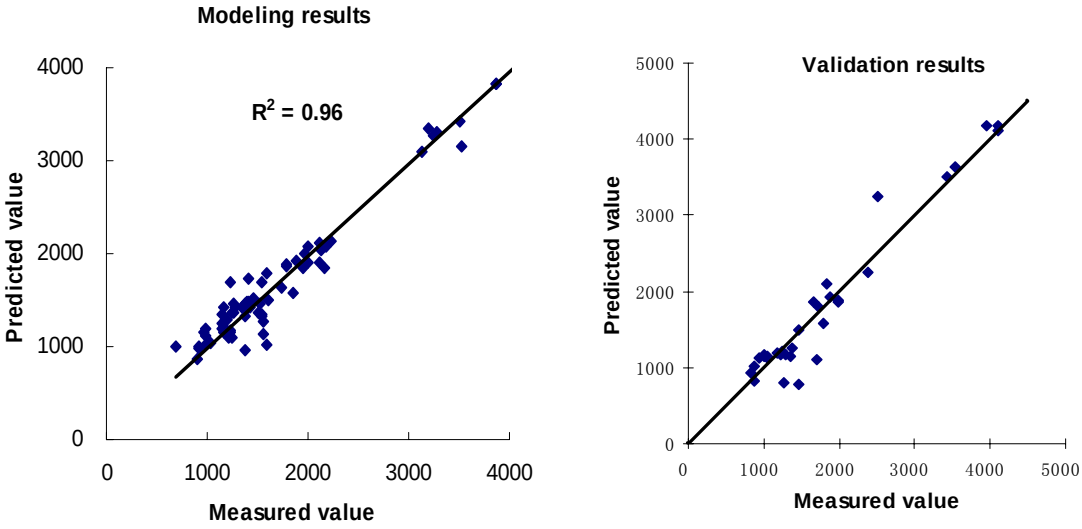


Figure 5.4.6 Modeling and validation results of H_2S emission for nursery

7) CO_2 concentration model (*CC*: ppm)

$$CC = 6364.3 - 2536.8V - 1575.5Ti + 108.63To - 200.36AU + 94.41V \times T + 6.723V \times To - 6.46V \times AU - 6.85Ti \times To + 9.24Ti \times AU + 0.36To \times AU$$

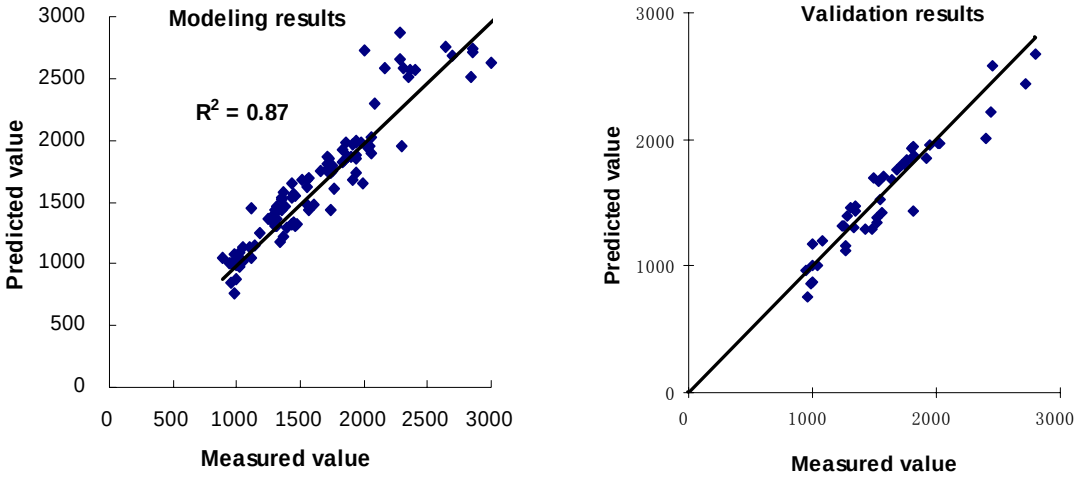


Figure 5.4.7 Modeling and validation results of CO_2 concentration for nursery

8) CO_2 emission model (CE: mg s^{-1})

$$CE = 7666.12 - 4732.5V - 249.9Ti + 249.7To - 20.1AU + 246.2V \times T - 63.8V \times To + 51.2V \times AU - 10.58Ti \times To - 0.64Ti \times AU + 1.79To \times AU$$

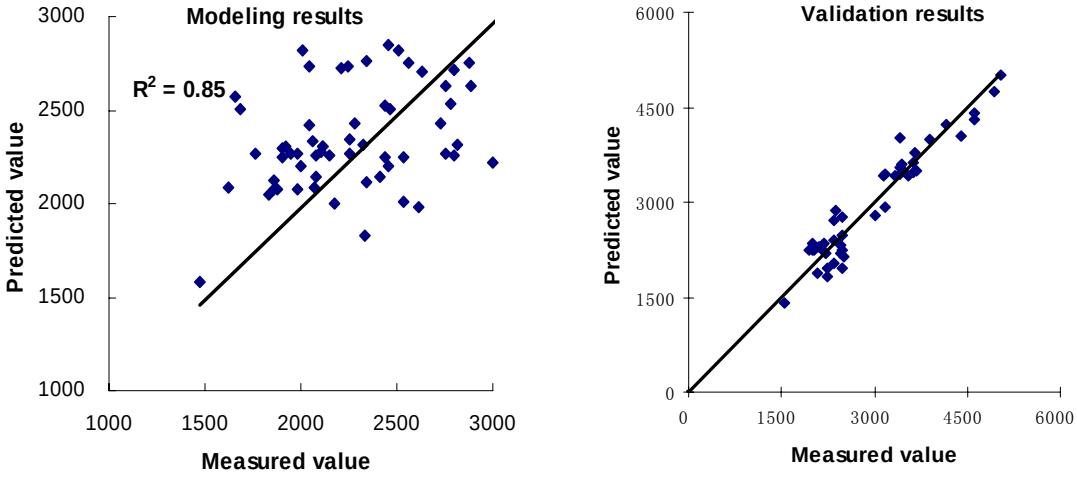


Figure 5.4.8 Modeling and validation results of CO_2 emission for nursery

9) CH_4 concentration model (CHC: ppm)

$$CHC = 795.6 - 286.5V - 28.93Ti + 30.8To - 36.05AU + 13.3V \times T + 1.55V \times To - 4.99V \times AU - 1.2Ti \times To + 2.01Ti \times AU - 0.72To \times AU$$

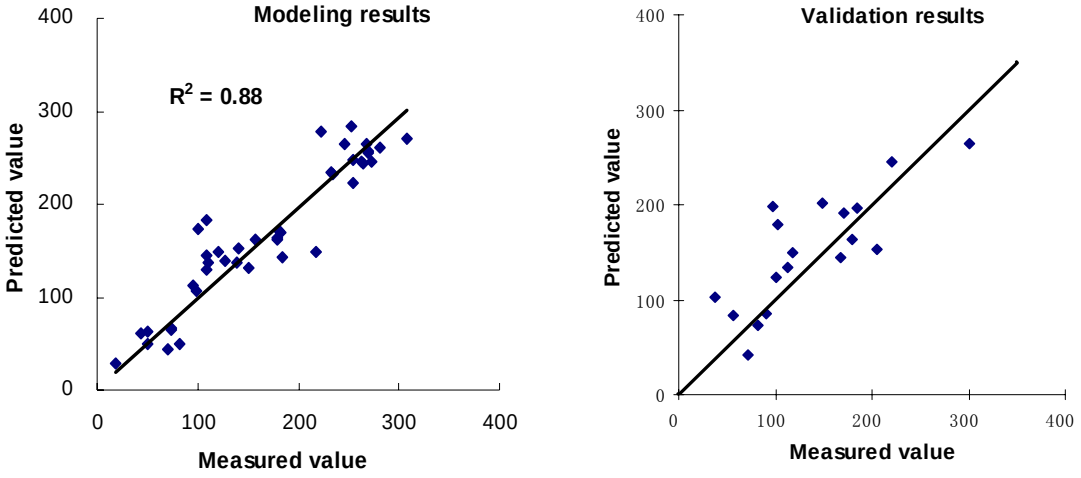


Figure 5.4.9 Modeling and validation results of CH_4 concentration for nursery

10) CH_4 emission model (*CHE*: mg s^{-1})

$$CHE = 413.45 - 300.03V - 23.16Ti + 23.74To + 18.11AU + 27.14V \times T - 7.43V \times To - 9.55V \times AU - 0.81Ti \times To - 0.58Ti \times AU - 0.17To \times AU$$

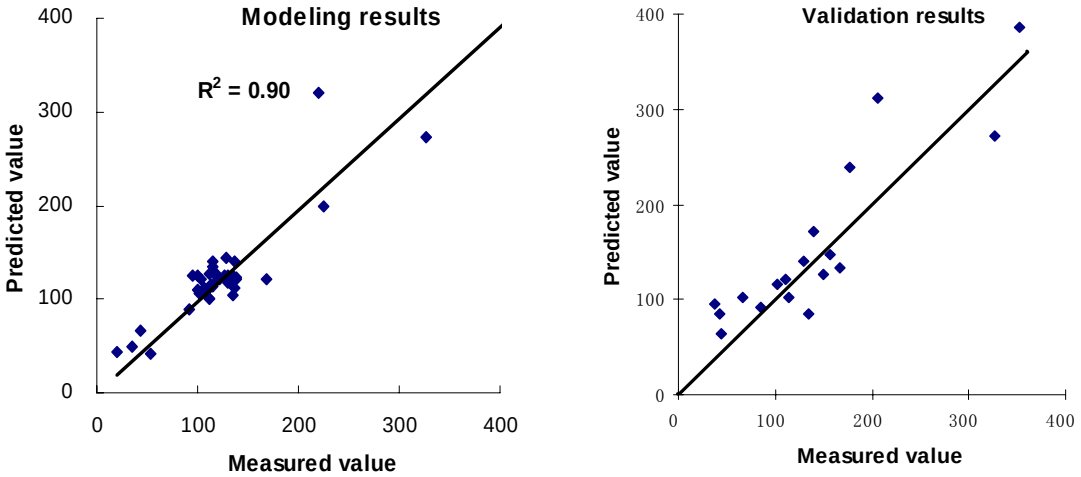


Figure 5.4.10 Modeling and validation results of CH_4 emission for nursery

5.4.2 Modeling results for the farrowing room

Table 5.4.2 provides the SPSS results for modeling part and validation part for farrowing. The R square varied from 0.56 for odour concentration model to 0.90 for CH_4 emissions model. Significances of t test were all larger than 0.05, except CO_2 concentration and emission models. Only the FB of CH_4 concentration and emission

models were larger than 0.25. The predictor of ventilation rate was excluded from the model. One reason might be it had close relationship with outside temperature and inside temperature that it could be expressed by those two factors.

1) Odour concentration model (OC: OU m^{-3})

$$OC = 18134.02 - 843.6Ti + 119.2To - 2808.46AU + 71.63V \times Ti 34.5V \times To - 100.1V \times AU - 3.11Ti \times To + 149.8Ti \times AU - 21.87To \times AU$$

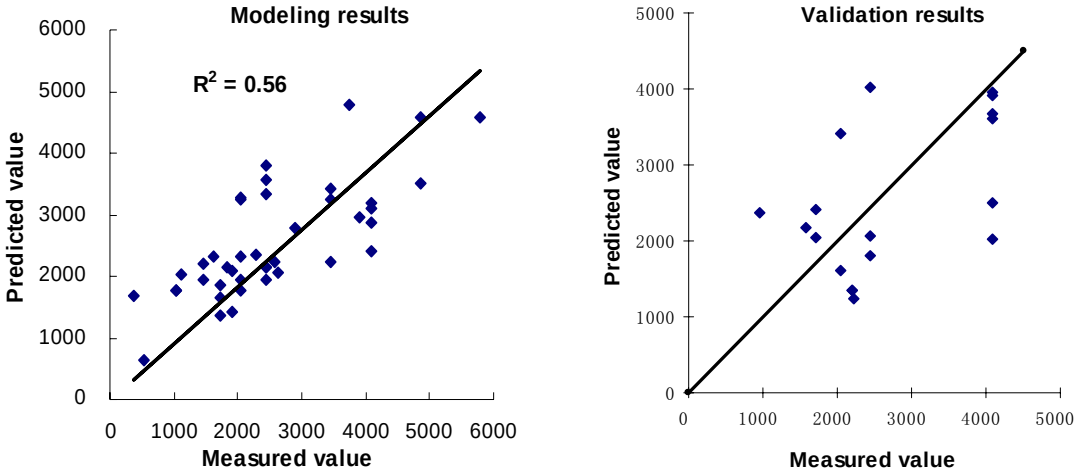


Figure 5.4.11 Modeling and validation results of odour concentration for farrowing

2) Odour emission model (OE: OU s^{-1})

$$OE = 41005.3 - 1698.74Ti - 403.3To - 6569.7AU + 51.26V \times Ti - 157.02V \times To + 633.3V \times AU + 17.22Ti \times To + 265.79Ti \times AU - 0.974To \times AU$$

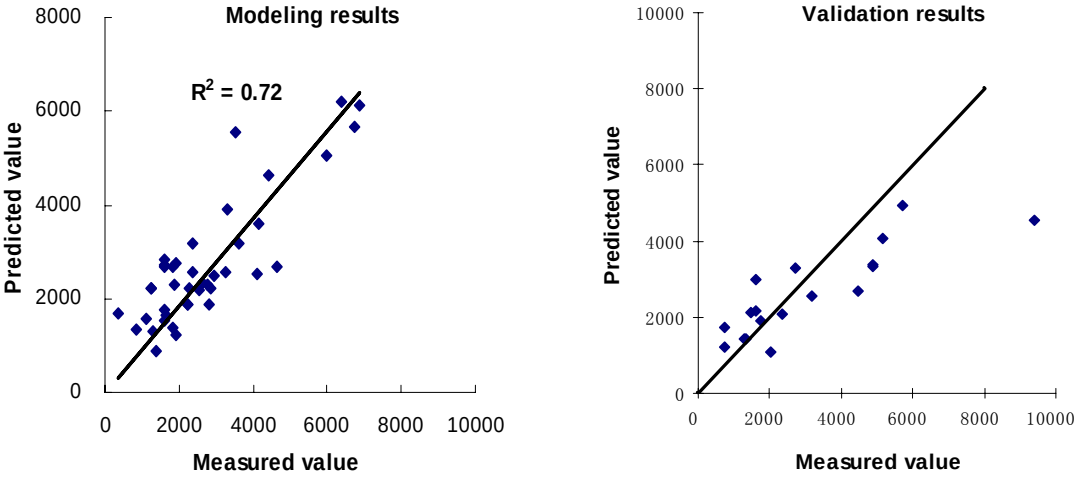


Figure 5.4.12 Modeling and validation results of odour emission for farrowing

Table. 5.4.2 SPSS results for modeling part and T test and FB test for validation part for farrowing room

Dependent variable	Modeling Part							Validation part					
								T test					FB
	R^2	C.V	Root MSE	V	Ti	To	AU	Mean difference	S.D	T value	df	p-value	
Odour Con ($OU\,m^{-3}$)	0.56	36.1	922.9	N/A	NS	NS	NS	170	1008	0.72	16	0.48	-0.065
Odour ER ($OU\,s^{-1}$)	0.72	49.9	948.9	N/A	NS	NS	NS	464.15	1438.83	1.37	17	0.19	-0.163
NH_3 Con (ppm)	0.95	61.4	1.24	N/A	N/A	NS	S	0.14	1.57	0.71	60	0.48	-0.016
NH_3 ER ($mg\,s^{-1}$)	0.69	26	0.94	N/A	N/A	S	S	0.38	2.17	1.01	60	0.31	-0.051
H_2S Con (ppb)	0.69	36	131.5	N/A	N/A	S	NS	8.76	139.93	0.35	30	0.73	-0.016
H_2S ER ($ug\,s^{-1}$)	0.61	27	216.7	N/A	N/A	NS	NS	9.25	190.46	0.27	31	0.78	-0.01
CO_2 Con (ppm)	0.86	28.9	150.7	N/A	S	NS	S	81.34	196.57	2.81	45	0.007	-0.067
CO_2 ER ($mg\,s^{-1}$)	0.81	38.9	264.8	N/A	S	S	S	95.02	307.48	2.1	45	0.04	-0.07
CH_4 Con (ppm)	0.78	32.3	23.7	N/A	N/A	NS	S	-33.82	74.23	-1.99	18	0.06	0.258
CH_4 ER ($mg\,s^{-1}$)	0.90	73.2	26.4	N/A	N/A	NS	NS	-36.07	92.28	-1.7	18	0.11	0.387

Note: Con=concentration; ER=emission rate; S= Independent variable had significant effect on dependent variable ($p<0.05$)

NS=Independent variable had no significant effect on dependent variable ($p>0.05$)

N/A= not available; C.V=coefficient of variation; Root MSE= root of mean square error

Mean difference= Measured value- predicted value

FB= fractional bias

3) NH_3 concentration model (*NC*: ppm)

$$NC = -11.08 - 0.515To + 4.28AU - 0.075V \times Ti + 0.22V \times To - 0.65V \times AU - 0.00038Ti \times To - 0.015Ti \times AU + 0.018To \times AU$$

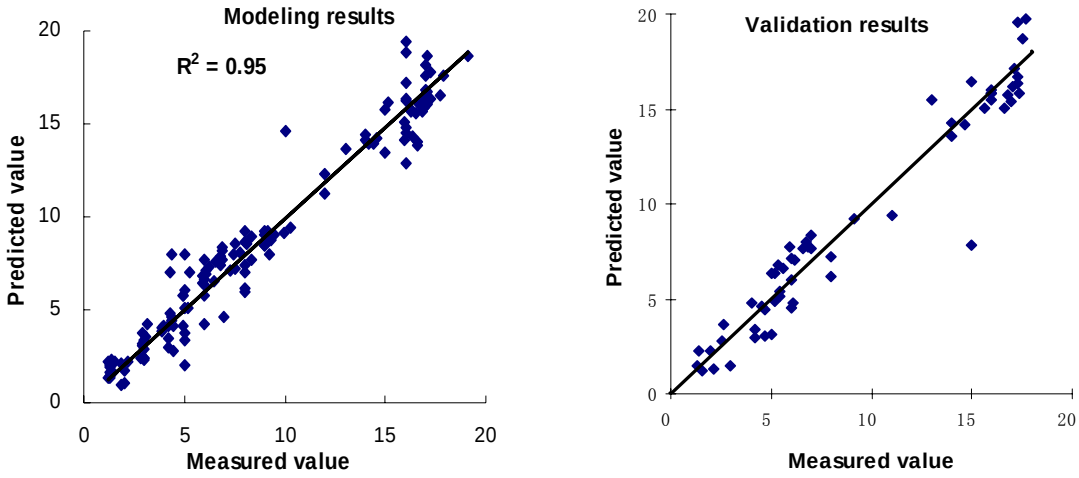


Figure 5.4.13 Modeling and validation results of NH_3 concentration for farrowing

4) NH_3 emission model (*NE*: mg s^{-1})

$$NE = -12.1 - 1.41To + 2.054AU - 0.03V \times Ti - 0.16V \times To + 0.7V \times AU + 0.019Ti \times To + 0.05Ti \times AU + 0.152To \times AU$$

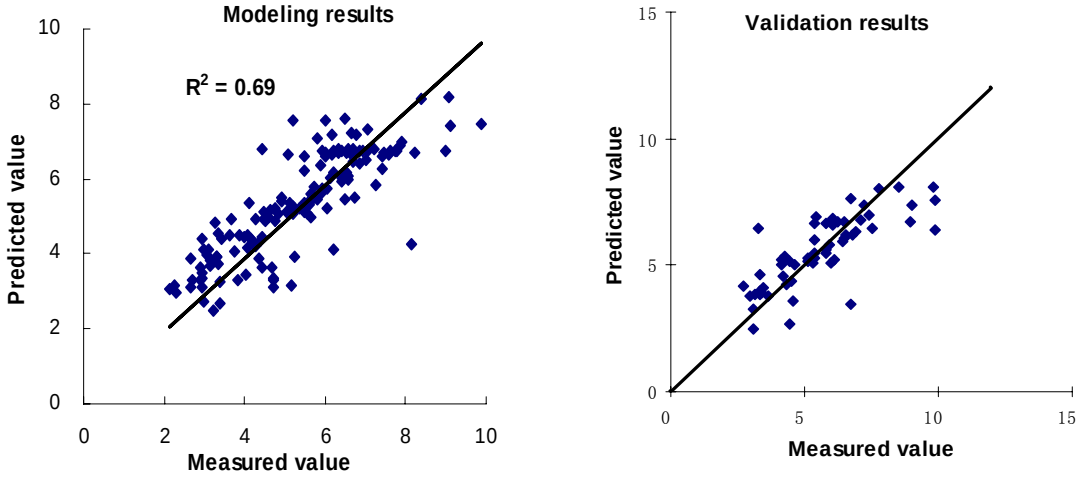


Figure 5.4.14 Modeling and validation results of NH_3 emission for farrowing

5) H_2S concentration model (*HC*: ppb)

$$HC = 1060.82 - 104.063To + 67.14AU + 37.3V \times Ti + 3.61V \times To - 178.62V \times AU$$
$$- 2.89Ti \times To - 3.61Ti \times AU + 25.62To \times AU$$

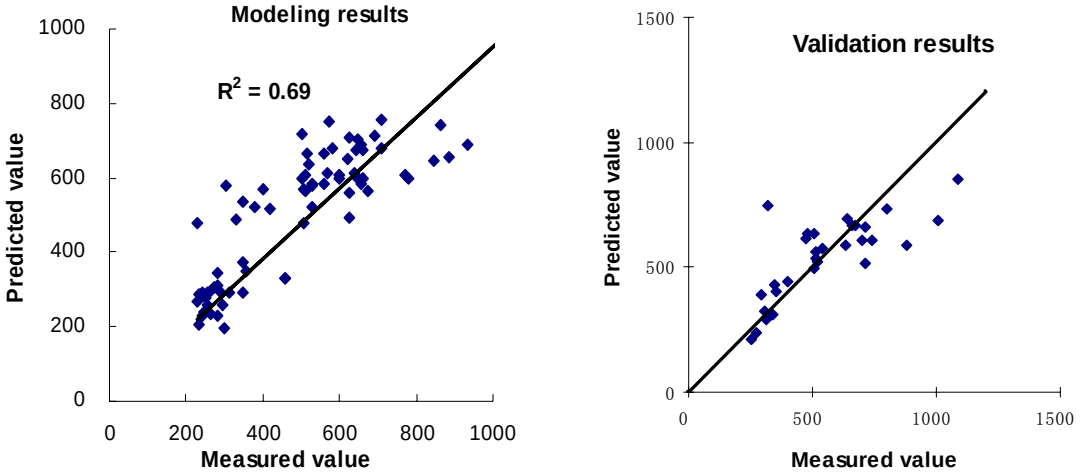


Figure 5.4.15 Modeling and validation results of H_2S concentration for farrowing

6) H_2S emission model (HE: ug s^{-1})

$$HE = 872.1 - 58.34To + 33.82AU + 40.0V \times Ti - 20.65V \times To - 47.66V \times AU$$
$$- 1.54Ti \times To - 5.03Ti \times AU + 17.43To \times AU$$

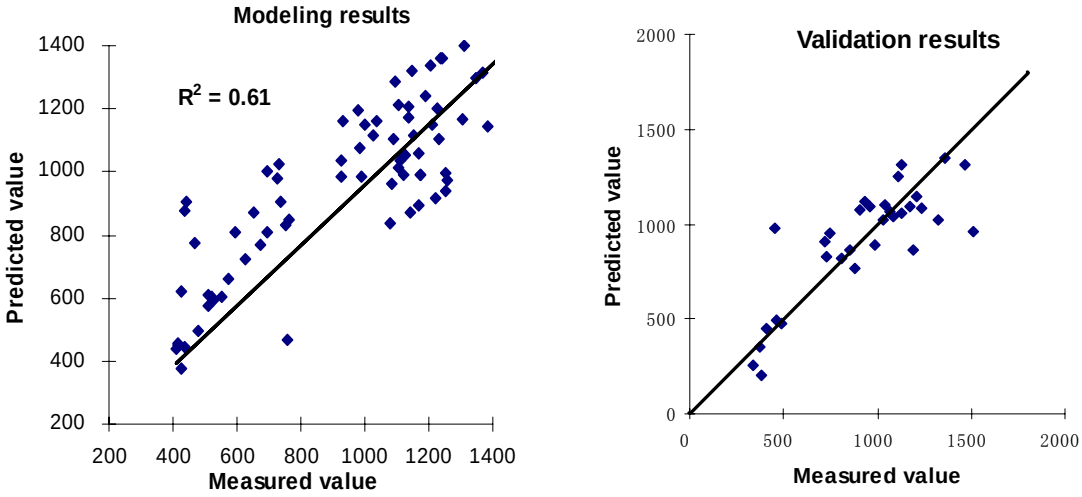


Figure 5.4.16 Modeling and validation results of H_2S emission for farrowing

7) CO_2 concentration model (CC: ppm)

$$CC = -22065.1 + 893.25Ti - 71.0To + 3290.94AU + 6.8V \times Ti + 16.78V \times To$$
$$- 109.7V \times AU - 4.41Ti \times To - 119.5Ti \times AU + 20.58To \times AU$$

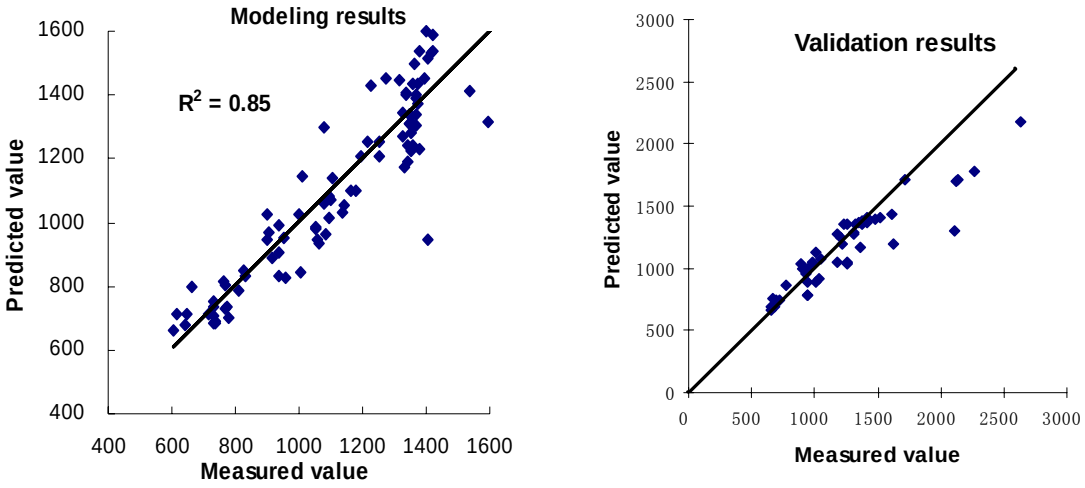


Figure 5.4.17 Modeling and validation results of CO_2 concentration for farrowing

8) CO_2 emission model (CE: mg s^{-1})

$$CE = -76661.2 + 3113.61Ti - 208.24To + 10963.4AU - 54.55V \times Ti - 18.14V \times To + 265.45V \times AU - 1.97Ti \times To - 439.28Ti \times AU + 39.2To \times AU$$

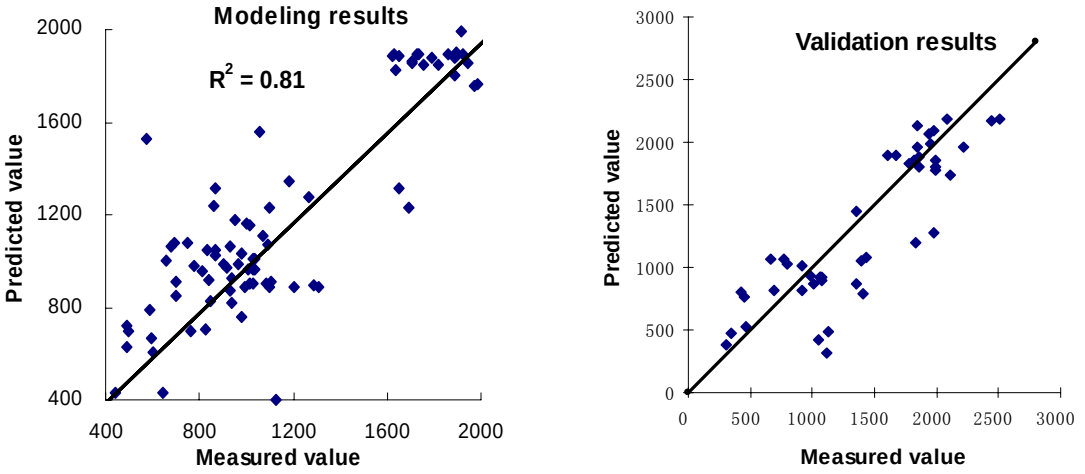


Figure 5.4.18 Modeling and validation results of CO_2 emission for farrowing

9) CH_4 concentration model (CHC: ppm)

$$CHC = 498.06 + 10.58To - 51.72AU - 6.21V \times Ti + 8.838V \times To + 5.98V \times AU + 0.59Ti \times To + 0.322Ti \times AU - 3.266To \times AU$$

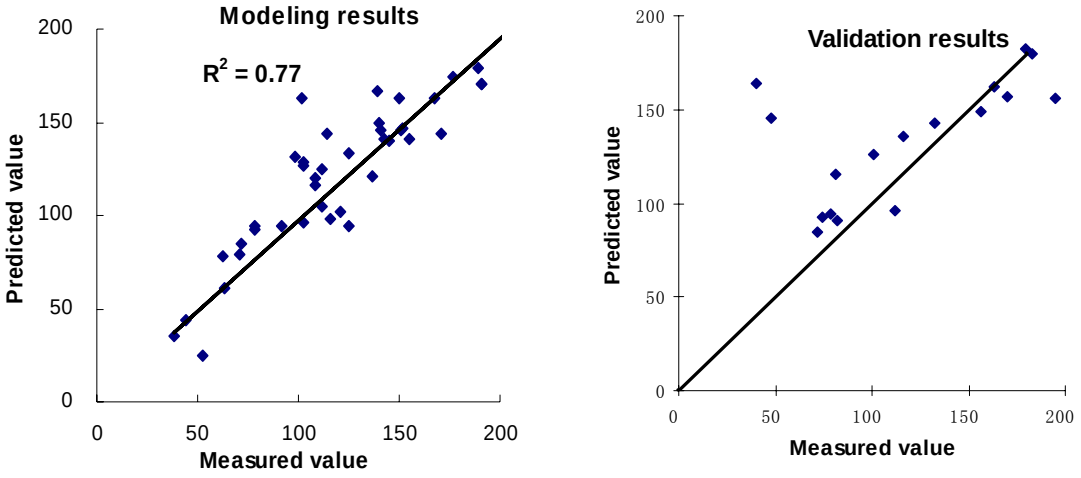


Figure 5.4.19 Modeling and validation results of CH_4 concentration for farrowing

10) CH_4 emission model (*CHE*: mg m^{-2} s^{-1})

$$CHE = 213.84 - 1.345To - 20.19AU - 0.284V \times Ti - 0.044V \times To - 1.052V \times AU + 0.682Ti \times To - 0.082Ti \times AU - 1.51To \times AU$$

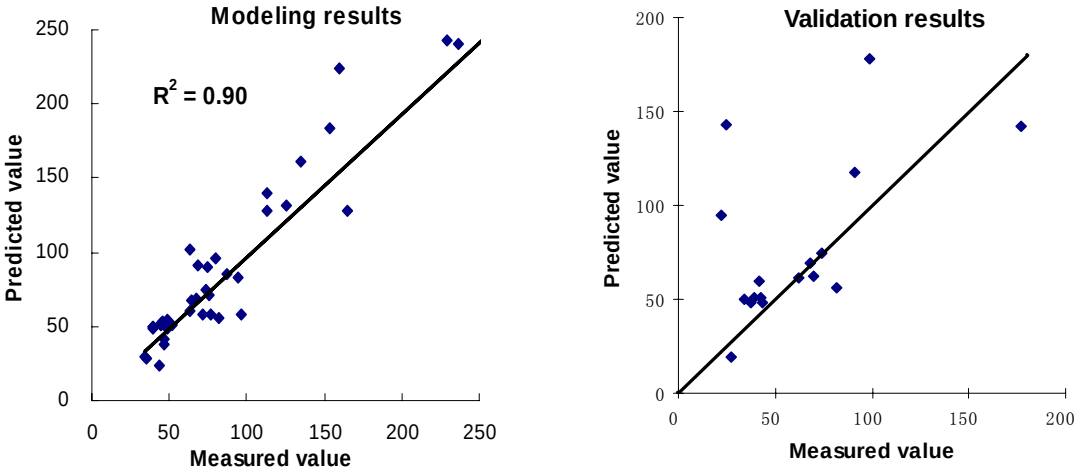


Figure 5.4.20 Modeling and validation results of CH_4 emission for farrowing

5.4.3 Modeling results for the gestation room

The modeling and validation results of odour and gas concentrations and emission models for the gestation room are provided in Table 5.4.5. The R square of statistical models varied from 0.64 to 0.91. Only the significance of t test for NH_3 emission model

was less than 0.05, while all the FB of models fell into the range of -0.25 <FB< 0.25, which demonstrated that the prediction model was acceptable.

1) Odour concentration model (*OC*: OU m^{-3})

$$OC = -10703.5 + 17.92V + 79.88AU - 2.04V \times Ti + 1.37V \times To - 2.67Ti \times To + 0.638Ti \times AU + 0.451To \times AU$$

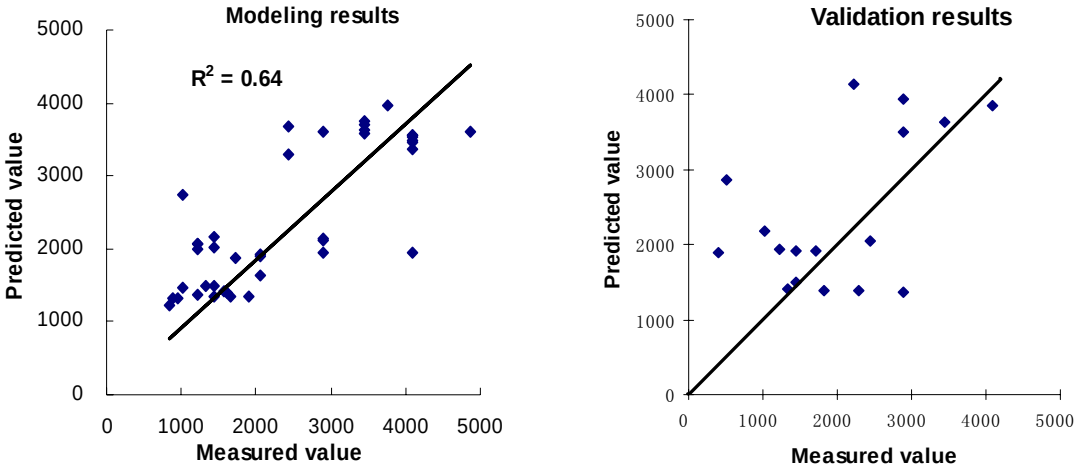


Figure 5.4.21 Modeling and validation results of odour concentration for gestation

2) Odour emission model (*OE*: OU s^{-1})

$$OE = -36108.7 + 1903.52V + 186.8AU - 68.23V \times Ti + 52.8V \times To - 44.4Ti \times To + 5.469Ti \times AU + 7.2To \times AU$$

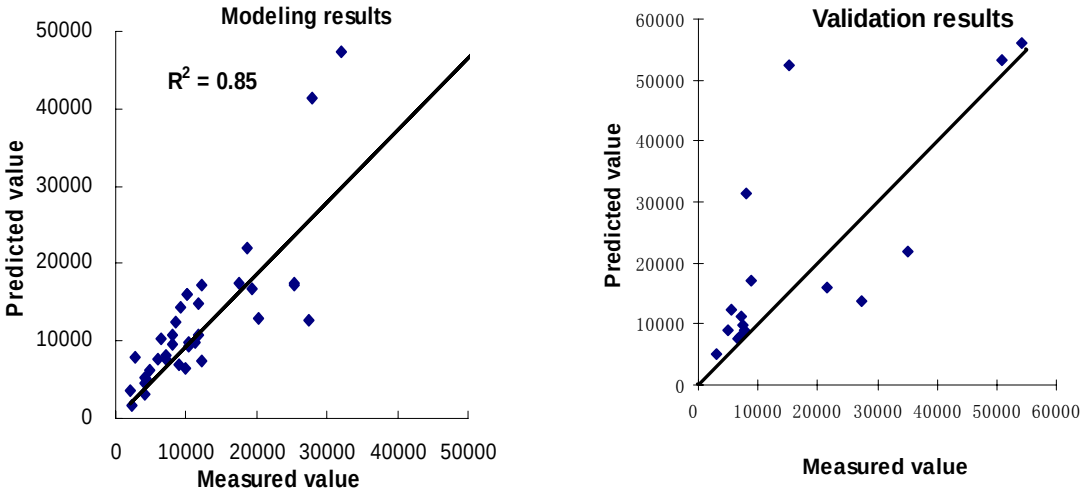


Figure 5.4.22 Modeling and validation results of odour emission for gestation

Table. 5.4.2 SPSS results for modeling part and T test and FB test for validation part for gestation room

Dependent variable	Modeling Part							Validation part					
								T test					FB
	R^2	C.V	Root MSE	V	Ti	To	AU	Mean difference	S.D	T value	df	P-value	
Odour Con ($OU\ m^{-3}$)	0.64	39.7	791.6	NS	N/A	N/A	NS	-398.84	999.07	-1.64	16	0.12	0.181
Odour ER ($OU\ s^{-1}$)	0.85	91.2	7093.7	NS	N/A	N/A	NS	-2672.06	13035.5	-0.85	16	0.41	0.125
NH_3 Con (ppm)	0.89	56.6	2.6	NS	N/A	N/A	S	-0.06	2.78	-0.16	60	0.88	0.004
NH_3 ER ($mg\ s^{-1}$)	0.69	47.4	16.4	S	N/A	N/A	NS	-9.25	17.13	-4.22	60	0.00	0.174
H_2S Con (ppb)	0.72	60.3	91.9	NS	N/A	NS	S	-18.22	110.1	-0.94	31	0.36	0.049
H_2S ER ($ug\ s^{-1}$)	0.91	59.1	1321.9	S	N/A	NS	NS	-241.45	1849.54	-0.74	31	0.47	0.036
CO_2 Con (ppm)	0.78	33.4	251.6	NS	N/A	NS	NS	-36.74	220.55	-1.14	46	0.26	0.027
CO_2 ER ($mg\ s^{-1}$)	0.66	30.3	2554.7	S	N/A	S	NS	-725.81	3108.82	-1.6	46	0.11	0.063
CH_4 Con (ppm)	0.70	48.3	26.3	S	N/A	N/A	NS	1.19	27.74	0.18	16	0.86	-0.016
CH_4 ER ($mg\ s^{-1}$)	0.91	147.9	370.6	S	N/A	N/A	S	83.41	316.27	1.09	16	0.29	-0.143

Note: Con=concentration; ER=emission rate; S= Independent variable had significant effect on dependent variable ($p<0.05$)

NS=Independent variable had no significant effect on dependent variable ($p>0.05$)

N/A= not available; C.V=coefficient of variation; Root MSE= root of mean square error

Mean difference= Measured value- predicted value

FB= fractional bias

3) NH_3 concentration model (*NC*: ppm

$$NC = -57.624 + 1.11V + 0.58AU + 0.0082V \times Ti - 0.0115V \times To - 0.00014V \times AU + 0.01144Ti \times To - 0.00459Ti \times AU - 0.000257To \times AU$$

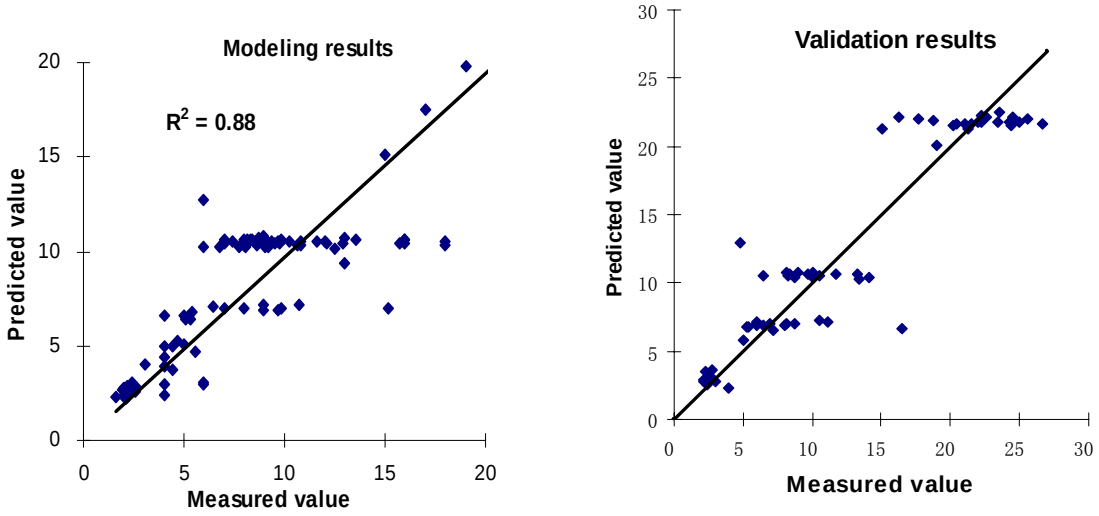


Figure 5.4.23 Modeling and validation results of NH_3 concentration for gestation

4) NH_3 emission model (*NE*: mg s^{-1})

$$NE = 26.94 - 25.76V - 0.1006AU - 0.34V \times Ti - 0.0073V \times To + 0.28V \times AU + 0.17Ti \times To - 0.00027Ti \times AU - 019To \times AU$$

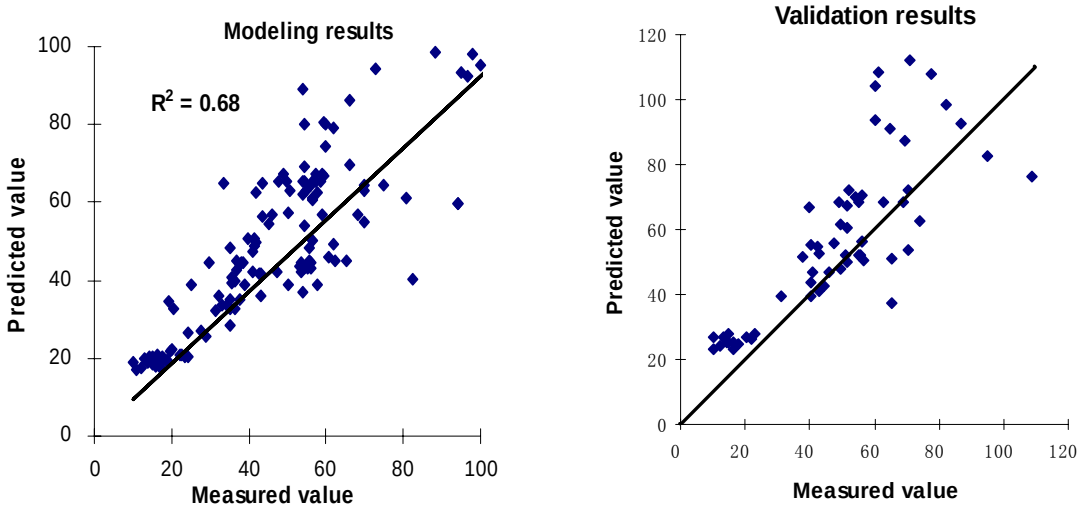


Figure 5.4.24 Modeling and validation results of NH_3 emission for gestation

5) H_2S concentration model (*HC*: ppb)

$$HC = -726.77 + 14.835V - 30.7To + 12.50AU - 0.1188V \times Ti - 0.8543V \times To + 1.6Ti \times To - 0.25Ti \times AU + 0.074To \times AU$$

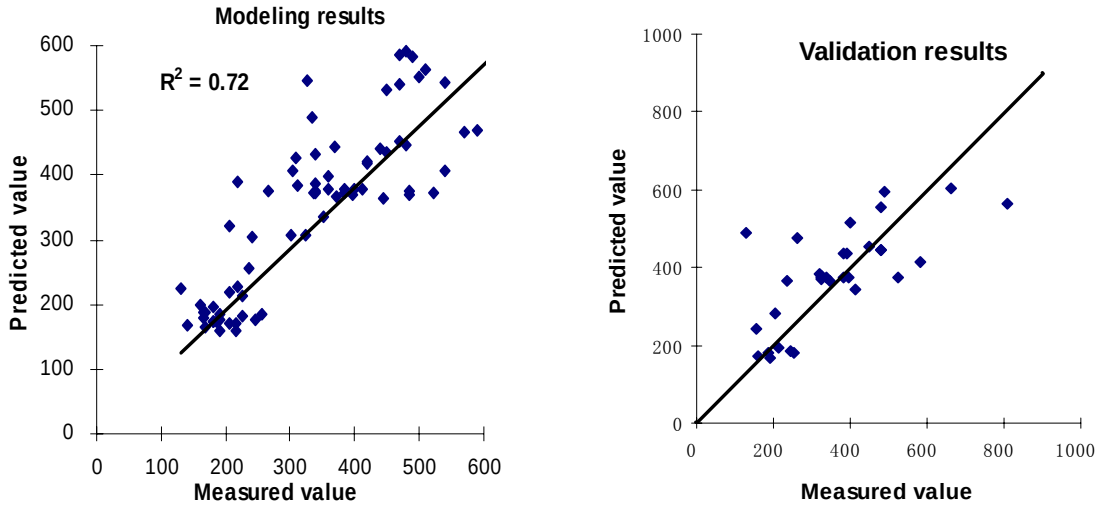


Figure 5.4.25 Modeling and validation results of H_2S concentration for gestation

6) H_2S emission model (HC: ug s^{-1})

$$HE = -10929.6 + 926.17V + 487.8Ti + 72.48AU - 9.4V \times Ti - 22.9V \times To + 22.2Ti \times To + -0.193Ti \times AU - 5.2To \times AU$$

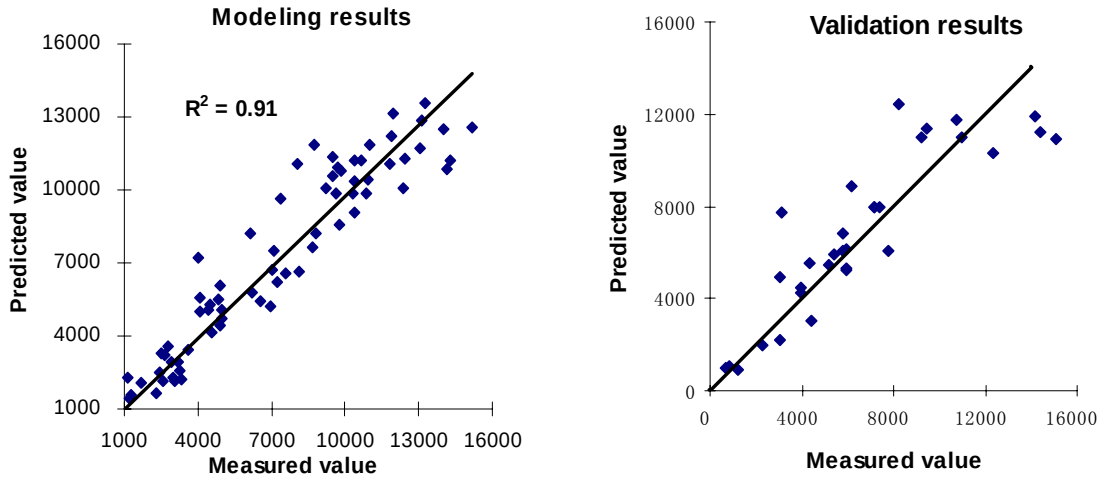


Figure 5.4.26 Modeling and validation results of H_2S emission for gestation

7) CO_2 concentration model (CC: ppm)

$$CC = -1203.04 - 43.12V - 40.6To - 18.77AU - 1.78V \times Ti + 3.42V \times To - 8.3Ti \times To + 2.28Ti \times AU + 1.03To \times AU$$

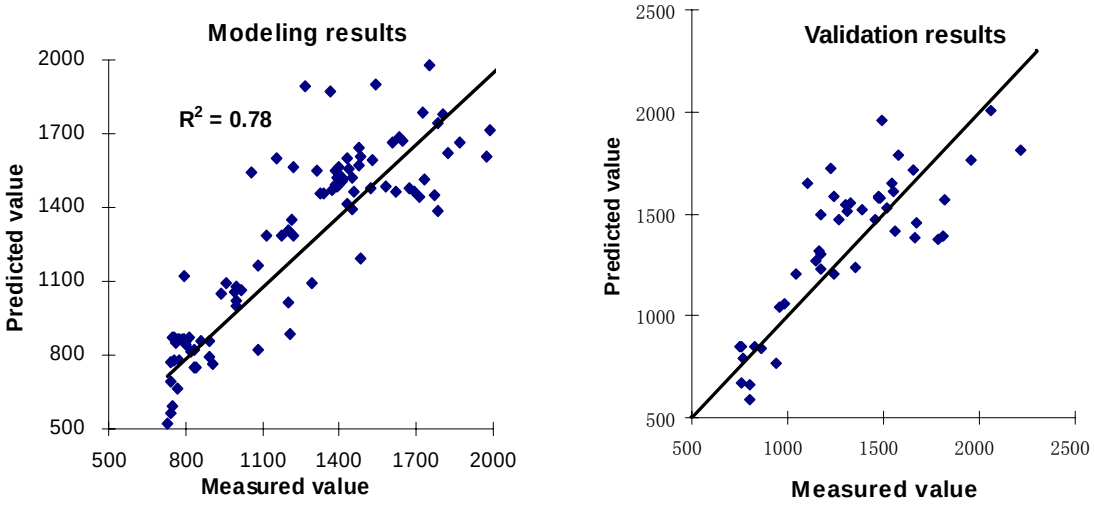


Figure 5.4.27 Modeling and validation results of CO_2 concentration for gestation

8) CO_2 emission model (CE: mg s^{-1})

$$CE = 1191.24 + 2090.3V - 3579.5To - 173.6AU - 108.4V \times Ti + 27.56V \times To + 22.33Ti \times To + 12.26Ti \times AU + 22.04To \times AU$$

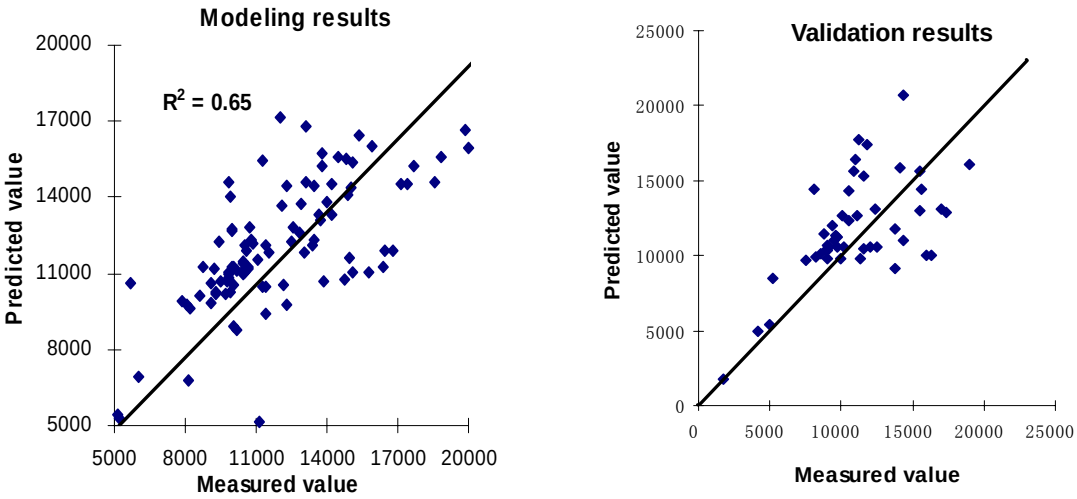


Figure 5.4.28 Modeling and validation results of CO_2 emission for gestation

9) CH_4 concentration model (CHC: ppm)

$$CHC = -315.5 + 90.21V + 2.84AU + 0.32V \times Ti - 0.77V \times To - 0.62V \times AU + 0.69Ti \times To - 0.029Ti \times AU - 0.078To \times AU$$

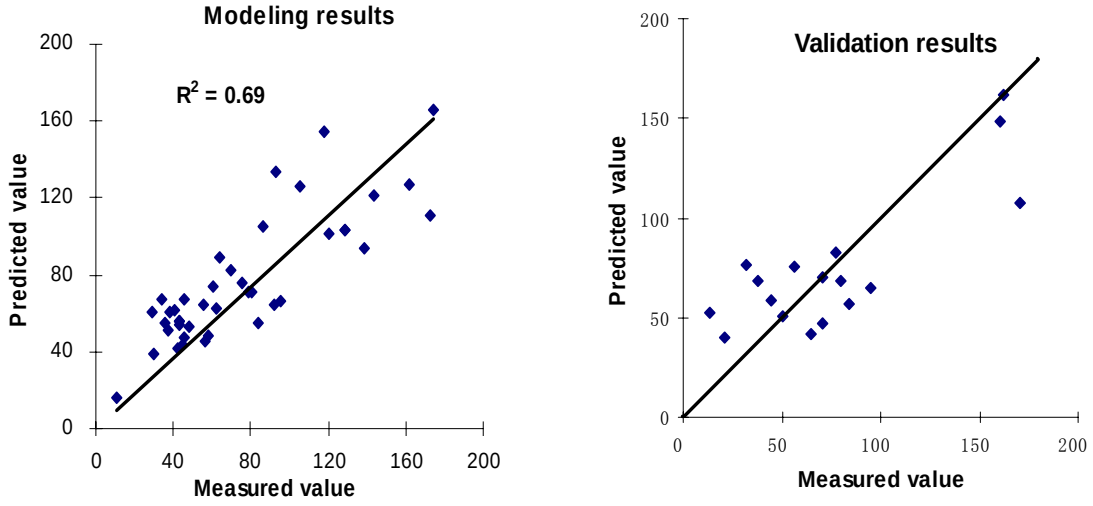


Figure 5.4.29 Modeling and validation results of CH_4 concentration for gestation

10) CH_4 emission model (*CHE*: mg s^{-1})

$$CHE = -6809.6 + 1625.34V + 48.77AU + 4.5V \times Ti - 6.36V \times To - 11.88V \times AU + 4.4Ti \times To - 0.15Ti \times AU - 0.26To \times AU$$

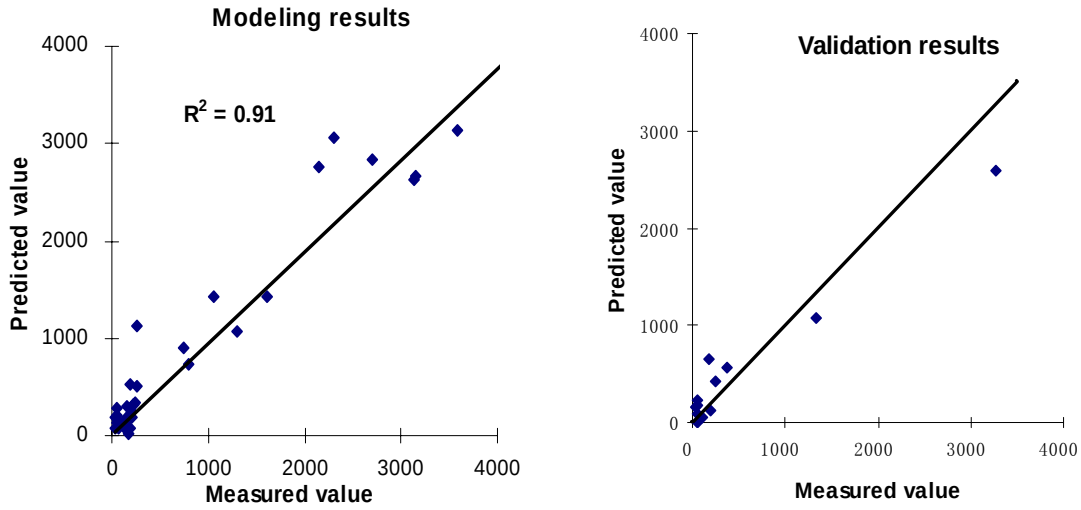


Figure 5.4.30 Modeling and validation results of CH_4 emission for gestation

5.4.4 Summary of modeling prediction

As given in Tables 5.4.1, 5.4.2, and 5.4.3, different dependent variables were affected by input factors (ventilation rate, ambient temperature, room temperature and animal unit) to various degrees. As a criterion to evaluate the fitness of prediction models, some R-

squares were up to 0.96, which indicated that the dependent variables might be predicted well by the models. Paired t test and fractional bias were two methods to validate the models. For most of the case, *P* values of significances of t test were larger than 0.05 and fractional bias fell into the range of -0.25<FB<0.25, which demonstrated that the there were no significant difference between predicted values and measured values and could be used to predict the dependent variables. The gas prediction models were better than the odour models which could be demonstrated by the comparison figures between measured data and predicted data. The excluded independent variables in the prediction models for the farrowing and gestation rooms resulted from two reasons, one might be its insignificant effect on dependent variables, the second might be that the independent variables exhibited close relationship with other parameters that they could be expressed by those parameters, e.g., *V* and *Ti* were closed related to each other and *To*.

6 SUMMARY AND CONCLUSIONS

The odour, gas and particulate matter emissions from swine production sites have become a great concern of the neighbouring communities due to the increasing scale of the sites. Public concerns regarding environmental impact and indoor air quality for workers and animals force the local governments and swine industry to obtain scientific emission information and adopt effective abatement technologies to help address these public concerns. Since odour is a major issue that the neighbouring communities complain the most, it is important to reduce its negative impact on the environment as well as public health. A widely accepted approach to ease the environment impact of odour and gas emissions is to maintain adequate setback distance between the operation sites and the neighbours. The setback distance is estimated by air dispersion models. Thus, the accurate measurement of baseline odour emission from various swine production facilities and building a database of odour and gas emissions for air dispersion models are essential to assess the nuisance potentials. In this study, three diurnal measurements and one year seasonal measurements were conducted. We found out that odour concentration varied diurnally in warm and mild weather, the peak level of odour concentration was 3-4 times of the lowest level in a daily course. For the seasonal variation, the odour concentration difference could reach tenfold. Regarding the odour emission, it varied diurnally and seasonally as well. Based on this finding, we should take multiple samplings of the odour under distinctive weather conditions in order to get more accurate odour emissions. The best sampling time for odour was recommended as the period of 12:00- 18:00 h because this period represented the worst situation of odour emission. From the estimation of total emission rates from all four types of rooms, it was found that the finishing area was the major odour source contributing 53% of the total emission. This study result provided the primary odour control target for the pork producers. The diurnal and seasonal measurement of NH_3, H_2S, CO_2, and dust provided a detail picture of indoor air quality for workers and animals. Generally, the indoor air quality in the nursery room had higher level than

farrowing and gestation room, but still below the exposure limit set by the Saskatchewan regulations.. However, workers in the swine barn should still take some protective measures avoiding long-term exposure and reduce the risk of health problems. Furthermore, the greenhouse gas emission from different areas of the swine barns was estimated.

6.1 Summary for Diurnal Odour and Gas Concentration and Emission

1) Three continuous 48-hours measurements conducted under warm, mild and cold weather conditions demonstrated that odour and gas concentrations in winter were higher than those in mild and warm weather conditions for all three types of swine rooms. Generally speaking, odour and gas concentrations and emission rates from the nursery room were higher than the other two types of rooms. No significant differences were observed between farrowing and gestation rooms in odour and gas concentrations and emissions.
2) Odour and gas concentrations and emissions exhibited large variations in August and April, which were highly correlated with the fluctuation of ventilation rates. High ventilation rate always corresponded to low concentrations and vice versa. The odour concentration level in midnight could be 3-4 times higher than the level in late afternoon. Diurnal factor had significant effects on odour or some gas concentrations and emissions in August and April ($P<0.05$), while not significant in February ($P>0.05$). The peak odour emission usually occurred during the period of 12:00 -18:00 h which could represent the worst situation of the day. Fairly apparent diurnal variation pattern were also observed in August and April in NH_3, H_2S and CO_2 concentrations being high in the early morning and low in the late afternoon. Ventilation rate played a key role in emission profiles.
3) Linear relationships were observed between odour concentration and NH_3, H_2S, and CO_2 concentrations, respectively, which indicated that odour concentration could increase with increase of these three gases. This study did not find any correlation between odour concentration and CH_4 concentration.

6.2 Summary for Seasonal Odour and Gas Concentrations and Emissions

4) The annual means of odour concentrations and emissions from the nursery, farrowing and gestation rooms were 3255 OU m^{-3} and 34.0 OU m^{-2} s^{-1}, 1990 OU m^{-3} and 16.1 OU m^{-2} s^{-1}; and 1540 OU m^{-3} and 10.2 OU m^{-2} s^{-1}, respectively. The profiles of odour and gas concentration and emissions in the annual course demonstrated that seasonal factor had significant effect on odour and gases (P<0.05). No specific variation pattern was observed except CO_2 concentration. However, for odour and NH_3, H_2S, CO_2 concentrations, high levels appeared in winter season while low levels occurred in summer.
5) The total greenhouse gas emission from all the rooms in the gestation, nursery and farrowing area was 2956 CO_2 equivalent tons per year, in which the gestation area, nursery area, and farrowing area accounted for 39.3 %, 37.2% and 23.5%, respectively. CO_2 contribution to the total greenhouse was 53.4%, higher than CH_4-CO2 equivalent value of 43.9%. Since the N_2O-$_{CO2}$ equivalent contribution was only 2.7%, it could be considered negligible as compared with CO_2 and CH_4.
6) Significant variation of total dust concentrations and dust depositions were observed in all rooms. The dust level in the nursery room was significantly higher than the farrowing and gestation rooms (P<0.05), while no statistically difference was found between the farrowing and gestation rooms (P>0.05). Dust deposition had a linear relationship with dust concentration (R^2=0.76).
7) Since seasonal and diurnal variations in odour, gas and dust concentrations and emissions were observed in this study, it is recommended to conduct multiple samplings during the day under different weather conditions in order to obtain representative source emission data.
8) Regarding air quality, the measured values were all below the exposure limits set by Saskatchewan Occupational Health and Safety Regulations. The maximum mean NH_3 H_2S, CO_2 concentrations were 13 ppm, 1.1 ppm, 2087 ppm while the exposure limits are 25 ppm, 10 ppm, 5000 ppm, respectively. The maximum mean total dust concentration was 2.42 mg m^{-3}, while its 8 h exposure limit is 10 mg m^{-3}. However, gas and dust were relatively high. As suggested by

Donhma et al (1995), air quality standard should be set up for animal industry specifically because the combined effect between different types of gases might have more potential impact on workers and animals.

6.3 Summary for Odour and Gas Concentrations and Emissions Modeling

The statistical models were developed to predict diurnal and seasonal odour and gas concentrations and emission rates for each type of rooms as determined by ventilation rate, room temperature, ambient temperature, and animal unit. The modeling results were agreeable with measured values in concentration and total emissions (R^2 within the range of 0.56 to 0.96). The paired t test and fractional bias were calculated to validate the modeling, most of t test significances the models were larger than 0.05 ($P>0.05$) and fractional bias fell into the range of $-0.25<FB<0.25$, which meant the models were acceptable.

.

6.4 Recommendations for Further Study

1) A literature review to summarize the odour and gas concentrations and emissions from swine barns is necessary. During the last few years, the diurnal and seasonal odour and gas concentrations and emission rates were monitored by the odour research group at the University of Saskatchewan extensively in two separate studies. There were also some snapshot measurements taken by University of Alberta and University of Manitoba on swine barns. Therefore, it is important to pool the data together for the Canadian Prairies.
2) Although the worker and animal activities and pen cleanliness were monitored during the experimental period, these influential factors were not considered in the statistical models. It is appropriate to quantify these factors with the help of other parameters e.g. monitoring heart rate of animal to represent the animal activity, which could be utilized in deriving statistical models to improve the accuracy.
3) Statistical model is one method to predict the odour and gas emissions rates but it can only be used for the specific experimental rooms. The analytical model based on steady-state heat and mass balance to predict the emission rates of the

buildings considering the meteorological data, indoor climate, airflow rates, animal conditions, etc. could be used for any rooms to predict the odour and gas concentrations and emission rates. Since a large quantity of odour data and hourly gas data were obtained from this study, use of neural network modelling probably is an alternative approach to correlate the odour and gas concentrations and emissions with the independent predictors.

4) Indoor air quality standard for livestock barns should be brought forward because the existing regulations only deals with the specific kind of gases existed within the buildings. However, there are several pollutants in the livestock buildings such as NH_3, H_2S, CO_2, CH_4, and dust. Their combined effect might have worse impact on workers and animals than any single gas. Indoor air quality index which considers a few contaminants should be introduced and serves for the livestock production barn section.

REFERENCES

At-anvisning No: 3.1.0.2 1992. Limiting Values of Compounds and Materials (in Danish). The Danish Labour Inspection Service, Landskronagade 33-35, 2100 Copenhagen East.

Albright, L.D. 1990. Environmental Control for Animals and Plants. St. Joseph, MI, UAS: ASAE.

AMCA Standard 210, ASHRAE Standard 51. 1999. Laboratory methods of testing fans for aerodynamic performance rating. Arlington Heights, Illinois.

Anon. 1994. Ammonia emissions to air in Western Europe, Technical Report No. 62. ECETOC, Brussels.

ASTM. 1998. E679-91. Standard practice for determination of odour and taste thresholds by a forced-choice ascending concentration series method of limits. In Annual Book of ASTM Standards.

ASTM. 2003. Standard guide for statistical evaluation of indoor air quality models. D5157-97 (Reapproved 2003). West Conshohocken, PA: ASTM International.

Barber, E.M., J.R. Dawson, V.A. Battams, and R.A.C. Nicol. 1991. Spatial variability of airborne and settled dust in a piggery. *Journal of Agricultural Engineering Research.* 50: 107-127.

Berckmans, D., J. Ni, J. Coenegrachts, and E. Vranken. 1994. Influence of the control of ventilation rate on ammonia emission in a pig house. ASAE Paper No. 944589. Atlanta, Georgia, USA: ASAE.

Bicudo, J.R., D.R. Schmidt, S.W. Gay, R.S. Gates, L.D. Jacobson, and S. J. Hoff. 2002. Air quality and emissions from livestock and poultry production waste management systems. *National Center for Manure and Animal Waste Management White Papers*, North Carolina State University, Raleigh, North Carolina, USA.

Bio-environmental and Structural Systems Lab. 2001. Fan test final report for Prairie Pride Enterprise. Department of Agricultural Engineering, University of Illinois, Illinois, USA.

Bottcher, R.W., K.M. Keener, R.D. Munilla, C.M. Williams, S.S. Schiffman. 2004. Dust and odour emissions from tunnel ventilation swine in North Carolina and comparison of different odour evaluation methods. *Applied Engineering in Agriculture*. 20: 343-347.

Canadian Pork Council, 2007. http://www.cpc-ccp.com/industry/statistics-farms.html Accessed September 25, 2007.

CEN. 1999. Air Quality Determination of Odour Concentration by Dynamic Olfactomery. PrEN 13725. Brussels, Belgium: European Committee for Standardization.

Chang C.W., H. Chung, C.F. Huang, and H.J. Su. 2001. Exposure assessment to airborne endotoxin, dust, ammonia, hydrogen sulphide and carbon dioxide in open style swine houses. *The Annals of Occupational Hygiene*. 45: 457-465.

Chaoui, H., M. Brugger. 2007. Comparison and sensitivity analysis of setback distance models. In International symposium on air quality and waste management for agriculture. Broomfield, Colorado, USA. ASABE Pub No. 701P907cd.

CIGR (Commission International du Genie Rura). 1994. Aerial Environment in Animal Housing.1994. Concentration in and emission from farm buildings, Rennes, CEMAGREF.

Climate change, 2001. IPCC Third Assessment Report.

Crook, B., J.F. Robertson, G.S. Travers, E.M. Botheroyd, J. Lacey, and M. D. Topping. 1991. Airborne dust, ammonia, microorganisms, and antigens in pig confinement houses and the respiratory health of exposed farm workers. *Am. Ind. Hyg. Assoc. J*. 52: 271–27.

Cuits, E.S., J.G. Drummond, K.W. Kelly, D.J. Grunloh, V.J. Meares, H.W. Norton, and A.H. Jen. 1975. Diurnal and annual fluctuation of aerial bacterial and dust levels in enclosed seine house. *Journal of Animal Science*.41 (5):1502-1511.

Curran, T.P., B.A. Sheridan, E.T. Hayes, and V.A. Dodd. 2002. Comparison of two dispersion models for odour nuisance prediction from pig units. *ASAE/CIGR Annual International Meeting*, Chicago, Paper No. 024014, July 28-31.

Day, D. L., E. Hansen, and S. Anderson. 1965. Gases and odours in confinement swine building. *Transactions of the ASAE*.8:118-121.

Donham, K. J., 1986. Hazardous agents in agricultural dusts and methods of evaluation. *American Journal of Industrial Medicine*.10:205-220.

Donham, K. J., T. D. Rubino, and J. Kammermeyer. 1977. Potential health hazards to agricultural workers in swine confinement building. *J. of Occ.Med*.19 (6): 383-387.

Donham, K., S. Reynolds, P. Whitten, J. Merchant. 1995. Respiratory dysfunction in swine production facility workers: dose-response relationship of environmental exposures and pulmonary functions. *Amer J Ind Med*. 27:405-423.

Doham, K.J., D.Cumro, S. Reynolds, J. Merchant. 2000. Dose-response relationships between occupational aerosol exposures and cross-shift decline of lung function in poultry workers: recommendations for exposure limits. *Journal of Occupational and Environmental Medicine*. 42: 260-269.

Environment Canada. 2003. Canada's Greenhouse Gas inventory 1990-2001. Official national greenhouse gas inventory submission to the United Nations Framework Convention on Climate Change (UNFCCC). Environment Canada. Ottawa, ON. 205 pages.

Environment Canada. 2007. http: // www. climate.weatheroffice.ec.gc.ca Accessed September 25, 2007.

Groot Koerkamp, P.W.G., J.H.M. Metz, G.H. Uenk, V.R. Phillips, M.R. Holden, R.W. Sneath, J.L. Short, R.P. White, J. Hartung, and J. Seedorf. 1998. Concentrations and emissions of ammonia in livestock buildings in Northern Europe. *Journal of Agricultural Engineering Research*. 70(1):79-95.

Gay, S.W., D.R. Schmidt, C.J. Clanton, K.A. Janni, L. D. Jacobson and S. Weisberg. 2003. Odour, total reduced sulphur, and ammonia emissions from animal housing facilities and manure storage units in Minnesota. *Applied Engineering in Agriculture* 19(3): 347-360.

Grubb, M., C. Vrolijk, D. Brack. 1999. The Kyoto Protocol: A Guide and Assessment, *The Royal Institute of International Affairs (RIIA),* London.

Guo, H., L.D. Jacobson, D.R. Schmidt, R.E. Nicolai, and K.A. Janni. 2001. Comparison of five models for setback distance determination. ASAE Paper No.01-4045. St. Joseph, Mich.: ASAE.

Guo, H., Jacobson, L.D., Schmidt, D.R., Nicolai, R.E., Janni, K.A. 2004. Comparison of five models for setback distance determination from livestock sites. *Canadian biosystems engineering*, 46(6), 17-25.

Guo, H., L.D. Jacobson, D.R. Schmidt, R.E. Nicolai, J. Zhu, and K.A. Janni. 2005. Development of the OFFSET model for determination of odour-annoyance-free setback distances from animal production sites: Part II. Model development and evaluations. *Transactions of the ASAE*. 48(6): 2269-2272.

Guo, H., Z. Yu, and C. Lague. 2006. Livestock odour dispersion modeling: a review. CSBE/SCGAS 2006 annual conference, Edmonton, Alberta, Paper No. 06-170. July 16-19.

Guo, H., W. Dehod, J. Agnew, C. Lague, J. R. Feddes, and S. Pang. 2006. Annual odour emission rate from different types of swine production buildings. *Transaction of ASABE*. 49(2): 517-525.

Gustafson, G. 1999. Factors affecting the release and concentration of dust in pig houses. *J. Agric. Eng. Research*. 74: 379-390.

Hartung, E.M., G. Brose, and T. Jungbluth. 1998. Diurnal course of the odour release from livestock housings and the odour reduction of biofilters. *Proceedings of International Conference on Odour, Water Quality, Nutrient Management and Socioeconomic Issues,* 299-304, Convention Complex, Des Moines, Iowa, USA. July 19-22.

Hayes, E.T., T.P. Curran, and V.A. Dodd. 2006. Odour and ammonia emissions from intensive pig units in Ireland. *Bioresource Technology*. 97: 940-948.

Heber, A.J., J.Q. Ni, B.L. Haymore, R.K. Duggirala, and K.M. Keener. 2001. Air quality and emission measurement methodology at swine finishing building. *Transactions of the ASAE*. 44(6): 1765–1778.

Heber, A. J., D. S. Bundy, T. T. Lim, J. Ni, B. L. Haymore, C. A. Diehl, and R. K. Duggirala. 1998. Odour emission rates from swine finishing buildings. In *Proc. Animal Production and Environment: International Conference on Odour, Water Quality, Nutrient Management and Socioeconomic Issues*, 298-305. Des Moines, Iowa. 19-22 July.

Heber, A. J., R. K. Duggirala, J. Q. Ni, M. L. Spence, B. L. Haymore, V.I. Adamchuck, D.S. Bundy, A.L. Sutton, D.T. Kelly, and K.M. Keener. 1997. Manure treatment to reduce gas emissions from large swine houses. In *Proc. International Symposium on Ammonia and Odours Control from Animal Production Facilities*, eds. J.A.M. Voermans and G. Monteny, 449-57. Vinkeloord, Rosmalen, The Netherlands: NVTL. 2.

Heber,A.J., M. Stroik, J.M. Faubion, L.H. Willard. 1988. Size distribution and identification of aerial dust particles in swine finishing buildings. *Transactions of the American Society of Agricultural Engineers*. 31(3), 882-887.

Heber, A. J., P. Tao, J. Ni, T. T. Lim, and A. M. Schmidt. 2005. Air emission from two swine finishing building with flushing: ammonia characteristics. *In Proceeding of the Seventh International Symposium.* Beijing, China. Paper No. 701P0205. 18-21 May.

Hoff, S.J., S. Bundy, and X. W. Li. 1997 Dust effects on odor and odor compounds. In Proc. International Symposium: Ammonia and odour control from Animal Production Facilities, Vinkeloord, October 6-10, Vol. 1, 101-110. J.A.M. Voermans and G. Monteny, eds. Rosmalen, The Netherlands: CIGR and EurAgEng publ.

Husted, S. 1993. An open chamber technique for determination of methane emission from stored livestock manure. *Atmospheric Environment*. 27(11): 1635-1642.

Husted, S. 1994. Seasonal variation in methane emission from stored slurry and solid manures. *Journal of Environmental Quality*. 23: 585-592.

Jacobson, L., D. Schmidt, and S. Wood. 2002. Odour From Feedlots Setback Estimation Tool.

Jacobson, L.D., S.L. Wood, D.R. Schmidt, A.J. Heber, J.R. Bicudo, and R.D. Moon. 2006. Site selection of animal operation using air quality criteria. In animal Agriculture and the Environment; National center for manure and animal waste management white paper. 505-528. St. Joseph, Michigan: ASABE. Pub.Number 913C0306.

Janni, K., L. Jacobson, D. Schmidt, K. Norlien, and T. Rosenstein. 2002. Livestock and poultry odour workshop proceedings. Department of Biosystems and Agricultural Engineering, University of Minnesota. St. Paul, MN, USA.

Janes, K. R., S.X. Yang, R.R. Hacer. 2005. Pork farm odour modeling using multiple-component multiple-factor analysis and neural networks. *Applied Computing*. (6): 53-61.

Jongebreur, A.A., G.J. Monteny, and N.W.M. Ogink. 2003. Livestock Production and Emission of Volatile Gases. In *International Symposium on Gaseous and Odour Emissions from Animal Production Facilities*, 11-30. Horsens, Denmark: CIGR, EurAgEng, NJF. 1-4 June.

Kim Ki Y., J. Ko Han, J. Lee Kyung, J. B. Parka, and N. KimChi. 2005. Temporal and spatial distributions of aerial contaminants in an enclosed pig building in winter. *Environmental Research*. 99: 150–157.

Laguë, C., E. Gaudet, J. Agnew, and T. A. Fonstad. 2004. Greenhouse Gas and Odour Emissions from Liquid Swine Manure Storage Facilities in Saskatchewan. ASAE Paper 04-4157. Conference presented at the 2004 Joint International Meeting of ASAE and CSAE/SCGR. St. Joseph, MI, USA.

Lemay, S. P. 1999. Barn management and odour control. *Advances in Pork Production*. (10): 81-91.

Lim T.T., A.J. Heber, J. Ni, R. Grant, A. Sutton. 2000. Odour impact distance guideline for swine production systems. In *proceedings of Odour and VOC Emissions 2000* (CD). Alexandria, VA: Water Environment Federation.

Lim, T.T, A. J. Heber, J. Q. Ni. A. L. Sutton, D. T. Kelly. 2001. Characteristics and emission rates of odour from commercial swine nurseries. *Transaction of ASAE*. 44 (5):1275-1282.

Lunn, F., J. Van De Vyver. 1977. Sampling and analysis of air in pig houses. *Agric. Environ*. 3: 159–169.

Maghirang, R.G., G.L. Riskowski, L. L. Christianson, and H.B. Manbeck. 1995. Dust control strategies for livestock buildings-a review. *ASHRAE Transactions* SD -95-15-1: 1161-1168.

Miller, G.Y; R.G. Maghirang, G. L. Riskowski, and A.J. Heber. 2004. Influences on air quality and odour from mechanically ventilated swine finishing buildings in Illinois. *Food, Agriculture & Environment*. 2(2): 353-360.

National Academy of Sciences. 2003. Air Emissions from Animal Feeding Operations: Current Knowledge, Future Needs. National Academies Press. Washington, D.C. 263 pp.

Ni, J.Q., A.J. Heber, T.T. Lim, R. Duggirala, B.L. Haymore, C.A. Diehl, and A.L. Sutton. 1998a .Hydrogen sulphide emissions from a large mechanically-ventilated swine building during warm weather. ASAE Paper No. 98-4051. St. Joseph, Mich.: ASAE.

Nimmermark, S., G. Gustafsson. 2004. Odour and Ammonia Release at Different Climatic Conditions in a Loose Housing System for Layers , *2004 ASAE/CSAE Annual International Meeting* Sponsored by ASAE/CSAE Fairmont Chateau Laurier, The Westin, Government Centre Ottawa, Ontario, Canada 1 – 4, August 2004.

NIOSH Manual of Analytical Methods (NMAM), Fourth Edition. 1994. Particulates not otherwise regulated, total. 0500.

Ogink, N.W.M., and P.W.G. Groot Koerkamp. 2001. Comparison of odour emissions from animal housing systems with low ammonia emission. *Water Science and Technology*. 43(11): 245-252.

Olson, D.K., S.M. Bark. 1996. Health hazards affecting the animal confinement farm worker. *Am.Assoc. Occup. Health Nurse J.*44:198-204.

O'Neill, D.H., and V.R. Phillips, 1991. A Review of the Control of Odour Nuisance from Livestock Buildings .1. Influence of the Techniques for Managing Waste within the Building. *J. Agric. Eng. Research*. 50: 1-10.

Osada, T., H.B. Rom, and P. Dahl. 1998. Continuous measurements of nitrous oxide and methane emission in pig units by infrared photo acoustic detection. *Transactions of the ASAE*. 41 (4): 1109 – 1114.

Parbst, K.E. 1998. Evaluation and particulate removal methods for controlling odour emissions from swine housing. North Carolina State University.

Parker, D.B., D.D. Schulte, and D.E. Eisenhasuer. 1999. Seepage from earthen animal waste ponds and lagoons- An overview of research results and state regulations. *Transactions of ASAE*. 42(2): 485-493.

Peu P., F. Beline, and J. Martinez. 1999. A floating chamber for estimating nitrous oxide emissions from farm scale treatment units for livestock wastes. *Journal of Agricultural Engineering Research*. 73: 101-104.

Phillips, V.R., D.S. Lee, R. Scholtens, J. A. Garland, and R. W. Sneath. 2001. A review of methods for measuring emission rates of ammonia from livestock buildings and slurry or manure stores, Part 2: monitoring flux rates, concentrations and airflow rates. *J. Agric. Eng. Res*. 78(1): 1–14.

Powers, W. 2003. Gaseous emissions from animal agriculture. Leaflet No. PM 1935. Iowa State University Extension.

Robertson, J.F. 1988. The influence of aerial contaminates on the severity of pip respiratory disease. In Aerosols-Their generation, behaviour and application. *Second conference of the Aerosol Society*, Great Britain.

Roger Phillips, V., R.W. Sneath, A.G. Williams, S.K. Welch, L.R. Burgess, T.G.M. Demmers, and J. L. Short. 1997. Measuring Emission Rates of Ammonia, Methane and Nitrous Oxide from Full-Sized Slurry and Manure Stores, in: Ammonia and Odour Control from Animal Production Facilities, *Proceedings of the International Symposium*, 197 - 208. AB Rosmalen. The Netherlands: NVTL.

Schauberger, G., M. Pringer, and E. Petz. 1999. Diurnal and Annual Variation of Odour Emission from Animal Houses: a Model Calculation for Fattening Pigs. *Journal of Agricultural Engineering Research*. 74: 251-259.

Schauberger, G. and M. Piringer. 1997a. Guideline to assess the protection distance to avoid annoyance by odour sensation caused by livestock husbandry. In *Proceedings of the Fifth International Symposium on Livestock Environment V*. Bloomington, Minnesota. May 29-31, 1997. Volume I. 170-178.

Schauberger, G. and M. Piringer. 1997b. Assessment of the protection distance to avoid annoyance by odour sensation caused by livestock husbandry by the Austrian guideline. In *Proceedings of the International Symposium: Ammonia and Odour Control from animal Production Facilities*. Vinkeloord, The Netherlands. October 6-10, 1997. 677-684.

Schiffman, S.S.1998. Livestock odours: implications for human health and well-being .*Journal of Animal Science.* 76: 1343-1355.

Schiffman, S.S., J.L. Bennett, J.H. Raymer. 2001. Quantification of odours and odorants from swine operations in North Carolina. *Agricultural and Forest Meteorology*. 108: 213-240.

Smith, J.H., C.R. Boon, and C.M. Wathes. 1993. Dust distribution and airflow in a swine house. *Proceedings of International Livestock Environment Symposium IV*, Warwick, England, *Transactions of ASAE*, 657-662.

SPSS 14.0. 2005. SPSS Inc, Chicago, USA.

Sun, G. 2005. Monitoring and Modeling Diurnal & Seasonal Odour and Gas Emission Profiles for Swine Barn. M.Sc. Thesis. University of Saskatchewan.

Takai, H., S. Perderson, and J.O. Johnsen. 1998. Concentrations and Emissions of Airborne Dust in Livestock Buildings in Northern Europe. *Journal of Agricultural Engineering resource*. (70): 59-77.

The Occupational Health and Safety Regulations. 1996. Saskatchewan regulations.

Townend, J. 2002. Practical statistics for environmental and biological scientists. West sussex, England: John Wiley & Sons Ltd.

USEPA. 1995a. User's Guide for the Industrial Source Complex (ISC3) Dispersion Models. Volumes I - III. EPA-454/B-95-003a-c.

USEPA. 1995b. A User's Guide for the CALPUFF Dispersion Model. EPA-454/B-95-006.

USEPA. 1998, A Comparison CALPUFF with ISCST3. EPA-454/R-98-020.

USEPA.2000. AUSPLUME GAUSSIAN PLUME DISPERSION MODEL USER MANUAL.

VDI 3471. 1986. Emissionsminderrung Tierhaltung - Hühner, Berlin: Beuth.

VDI 3472. 1986. Emissionsminderrung Tierhaltung - Schwein, Berlin: Beuth.

VDI 3473. 1986. Emissionsminderrung Tierhaltung - Rinder, Berlin: Beuth.

Verdoes, N., and, N.W.M. Ogink. 1997. Odour emission from pig houses with low ammonia emission. In *Proc. International Symposium: Ammonia and odour control from Animal Production Facilities*, Vinkeloord, 1: 317-325. J. A. M. Voermans and G. Monteny, eds. Rosmalen. The Netherlands: CIGR and EurAgEng publ. 6-10 October.

Williams, A. 1984. Indicators of piggery slurry odour offensiveness. *Agric. Wastes.* 10: 15–36.

Williams, M.L. and N. Thompson. 1986. The effects of weather on odour dispersion from livestock buildings and from fields. In *Odour prevention and control of organic sludge and livestock farming*. Eds. Nielsen, J.H. Voorburg and P. L'Hermite. London. Elsevier Applied Science Publishers. 227-233.

Williams, A.G. 1989. Dust and odour relationships in broiler house air. *Journal of Agricultural Engineering Research*. 44: 175-190.

Wood, S.L., D.R. Schmidt, K.A. Janni, L.D. Jacobson, C.J. Clanton, and S. Weisberg. 2001. Odour and air emissions from animal production systems. ASAE Paper No. 014043. St. Joseph Mich.: ASAE.

Zahn, J., A. DiSpirito, Y. Do, B. Brooks, D. Russel, E. Cooper. 2000. Correlation of human odour response magnitudes to air concentrations of malodorous volatile organic compounds associated with swine manure odour, in: *Odours and VOC Emissions 2000 Conference*.

Zhang, Q., J. Feddes, I. Edeogu, M. Nyachoti, J. House, D. Small, C. Liu, D. Mann, and G. Clark. 2002. Odour production, evaluation and control. Final report prepared for Manitoba Livestock Manure Management Initiatve Inc., Winnipeg, MB.

Zhang, Q., X.J. Zhou, N. Cicek, and M. Tenuta. 2007. Measurement of odour and greenhouse gas emissions in two swine farrowing operations. *Canadian Biosystems Engineering*. 49: 613-620.

Zhou, X., and Q. Zhang. 2003. Measurements of odour and hydrogen sulphide emissions from swine barns. *Canadian Biosystems Eng.* 45: 13-18.

Zhu, J., L.D. Jacobson, D.R. Schmidt, and R.E. Nicola. 1998. Modeling the agricultural odour dispersion using atmospheric dispersion model. ASAE paper No.98-4056. St.Joseph, Mich.:ASAE.

Zhu, J., L. Jacoboson, D. Schmidt, R. Nicolai. 2000. Daily variation in odour and gas emissions from animal facilities. *Applied Engineering in Agricultural*. 16 (2):153-158.

APPENDIX A

CALIBRATION OF THE SENSORS

A.1 Calibration of the Temperature Sensors

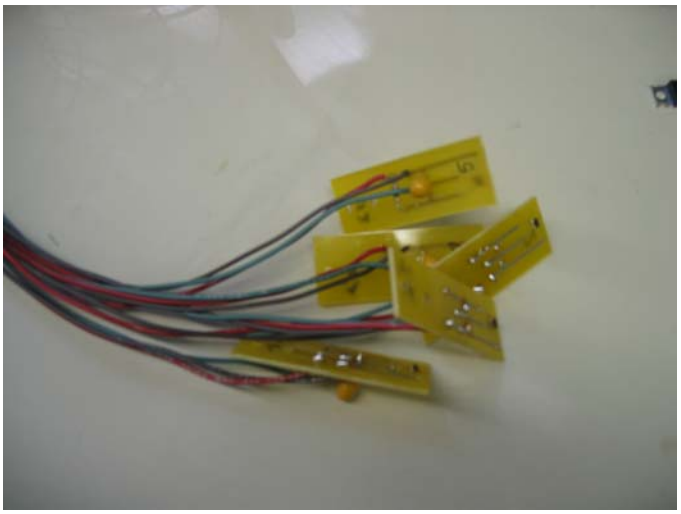


Figure A.1 Temperature sensors

Figure A.2 Calibration setup of temperature sensors

The temperature sensor (TC 1047, Microchip Technology Inc., Chandler, AZ, USA) is a linear voltage output sensor that could accurately measure temperature from -40℃ to

125℃ with 0.5 ℃ precision. Temperature calibration procedure was conducted in the Hardy lab in department of Agricultural and Bioresource Engineering, University of Saskatchewan. All five sensors were put in the climatic control chamber (B-M-A, Inc. AYER, MA, USA); adjusting the set point temperature from -15℃ to 35 ℃ by step of 5 ℃. All the data was recorded by CR10X data logger and displayed on the laptop. The calibration results between the voltage output and the temperature were listed in Table A.1

Table A.1 Calibration results of temperature sensors

Temperatur sensors	Calibration equation	R^2
Nursery room	V=9.0482T+491.61	0.9979
Farrowing room	V=8.9033T+489.15	0.9861
Breeding room 1	V=8.7158T+494.82	0.9986
Breeding room 2	V=8.6225T+494.02	0.9968
Outside	V=8.4551T+484.48	0.9934

Note: V is the voltage output of the sensors, mv; T is the temperature, ^{o}C

A. 2 Calibration of the Relative Humidity Sensors

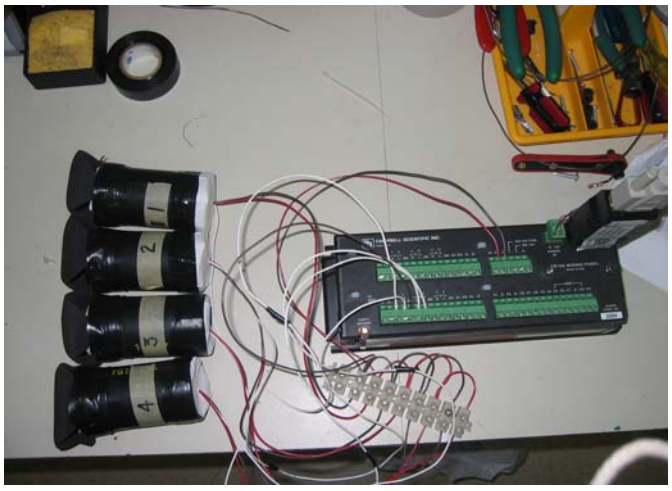


Figure A.3 Relative humidity sensors

Figure A.4 Calibration setup of relative humidity sensors

The RH sensors calibration was carried out at Thermodynamic lab, University of Saskatchewan. They were covered with PVC film to reduce the dust and light influence on the sensors. The 4 sensors were placed in a humidity generator (1200 humidity generator, Thunder scientific corporation, NM, USA). All the voltage readings were stored in the CR10X data logger. The RH set point is 40%, 50%, 60%, 70%, 80% and 90% under around 25 degree, respectively. The calibration results for relative humidity sensors were listed in Table A. 2

Table A.2 Calibration results of relative humidity sensors

Relative humidity sensors	Calibration equation	R^2
Nursery room	V=12.769RH+463.25	0.9982
Farrowing room	V=12.769RH+463.25	0.9992
Breeding room 1	V=12.1RH+498.25	0.9985
Breeding room 2	V=12.32RH+497.9	0.9986

Note: V is the voltage output of sensors, mv; RH is the relative humidity,%

A.3 Calibration of the Pressure Sensors

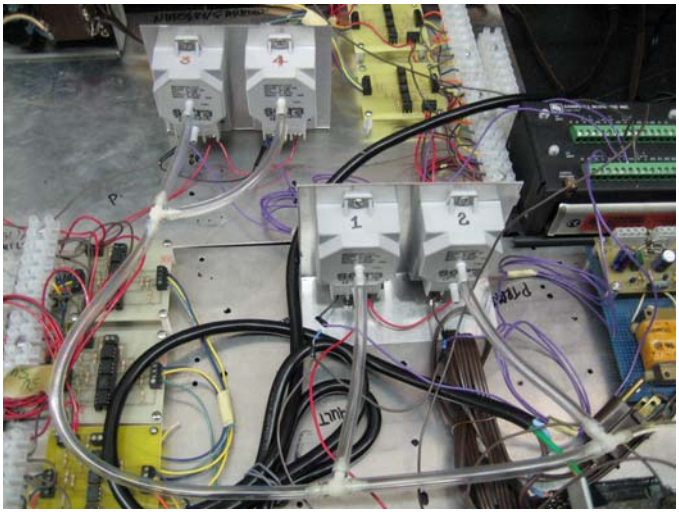


Figure A.5 Calibration setup of pressure transducers

The calibration of pressure transducers (Model 265, Setra system Inc, Boxborough, MA, USA) was conducted in the Fluid Dynamic Lab of University of Saskatchewan. The calibration system is comprised of precision pressure indicator/calibrator (Druck DPI 605) and manometer (34FB2TM, Meriam instrument, Div of the scott&Fetzer Co. Cleveland, Ohio, 44102, USA). Adjusting the front screw to change the inside Druck volume according to the manometer, the certain pressure is applied to the transducers. The calibration results were shown in Table A.3.

Table A. 3 Calibration results of pressure transducers

Pressure transducers	Calibration equation	R^2
Nursery room	V=6500.7P+395.35	0.9998
Farrowing room	V=6466.3P+393.13	0.9998
Breeding room 1	V=6490.4P+393.38	0.9998
Breeding room 2	V=6470.8P+389.68	0.9997

Note: V is the voltage output of sensors, mv; P is the pressure difference, inch water

A.4 Calibration of the Hall Position Sensors

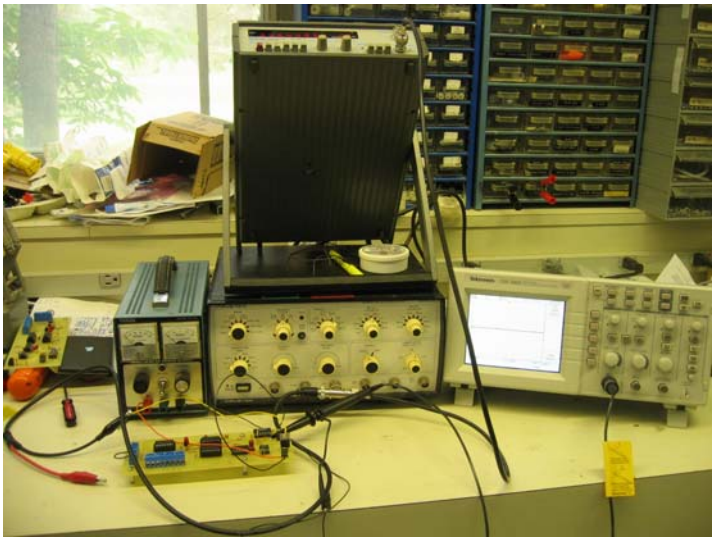


Figure A. 6 Calibration setup of Hall position sensors

The calibration of frequency and voltage output relationship was performed by pulse generator, frequency counter, oscilloscope and Digital multimeter. Pulse generated was applied to the frequency multiplier and frequency voltage converter board. The maximum RPM of Fan is 1700, its corresponding frequency is 29.So we adjust the frequency range from 5 to 30 to develop the relationship with its output voltage. The relationship between frequency and voltage output was listed in Table A. 4

Table A.4 Calibration results of Hall position sensors

Board	Calibration equation	R^2
Board A	Y=0.8116V-9.234	1
Board B	Y=0.7928V-7.6063	1
Board C	Y=0.7828V-10.037	1

Note: V is the voltage output of the sensors.mv; Y is the rotation speed, RPM

A.5 Calibration of the Dust Sampling Pumps

For total dust sampling, the flow rate is set to 2 L/ min. The calibration system included pocket flow calibrator (Series 580, Kurz instrument Inc.), Airlite personal sampling pump (SKC, USA) and cassette. The tared 37-μm PVC filter and filter pad were laid in the cassette. Adjusting the flow rate by screwdriver to 2 L/min which is monitored by flow calibrator.

Figure A.7 Calibration of personal sampling pump

APPENDIX B

VERIFICATION OF FAN FLOW RATE

In the field verification of fan flow rate, inlet opening was adjusted 100%, 50%, 25% and 0% to create different pressure difference across the fans. All the tested fans were running at full speed. Fan TR16 and TR 20 were tested in the nursery room, TR12 was tested in the farrowing room and TR 24, TR 36 were tested in gestation room. The fan curve method was calculated by knowing the pressure difference and fan speed. The relationship between air flow rate and pressure difference, fan speed was developed based on the fan testing report obtained from Bioenvironmental and Structural System Laboratory, Department of Agricultural Engineering, University of Illinois (2001). The fan testing report for each type of fan and their air flow rate equation were listed below.

Table B.1 Fan testing report of TR36 and its air flow rate equation

# Nozzle	Size (inch)	Pressure Drop	Static pressure (Inch water)	Air flow (cfm)	rpm
208v					
6	8	2.23	0	838	12653
6	8	1.99	0.05	833	11953
6	8	1.66	0.1	829	10916
6	8	1.36	0.15	836	9879
6	8	1.06	0.2	828	8719
6	8	0.68	0.25	829	6977
5	8	0.69	0.3	820	5835
230v					
6	8	2.33	0	848	12933
6	8	2.04	0.05	846	12087
6	8	1.76	0.1	845	11241
6	8	1.45	0.15	843	10202
6	8	1.14	0.2	843	9043
6	8	0.81	0.25	841	7618
6	8	0.53	0.3	838	6126

Air flow rate= -22914 × Pressure+ 13164

Table B.2 Fan testing report of TR24 and its air flow rate

# Nozzle	Size (inch)	Pressure Drop	Static pressure (Inch water)	Air flow (cfm)	rpm
3	8	2.53	0.00	1628	6704
3	8	2.35	0.05	1622	6455
3	8	2.14	0.10	1615	6159
3	8	1.97	0.15	1609	5917
3	8	1.78	0.20	1605	5616
3	8	1.58	0.25	1600	5298
3	8	1.37	0.30	1597	4933
3	8	2.26	0.00	1544	6330
3	8	2.05	0.05	1529	6028
3	8	1.84	0.10	1521	5710
3	8	1.62	0.15	1506	5357
3	8	1.39	0.20	1492	4960
3	8	1.18	0.25	1480	4577
3	8	1.84	0.00	1407	5710
3	8	1.57	0.05	1374	5273
3	8	1.3	0.10	1347	4805
3	8	1.06	0.15	1332	4338
3	8	0.9	0.20	1326	3985
3	8	0.71	0.25	1323	3547
3	8	1.16	0.00	1160	4538
3	8	0.89	0.05	1117	3962
3	8	0.66	0.10	1093	3419
2	8	1.02	0.15	1076	2830
2	8	0.65	0.20	1071	2262
1	8	1.46	0.25	1061	1698
2	8	1.25	0.00	862	3141
2	8	0.7	0.05	822	2348
1	8	1.23	0.10	800	1558
1	6	1.31	0.15	800	903
1	6	0.61	0.17	801	615
1	8	1.62	0.00	616	1788
1	6	1.29	0.05	595	896
1	6	0.59	0.07	591	605

Air flow rate=-2132.325-7280.769×Pressure+5.644 rpm

Table B.3 Fan testing report of TR20 and its air flow rate equation

# Nozzle	Size (inch)	Pressure Drop	Static pressure (Inch water)	Air flow (cfm)	rpm
2	8	3.08	0.00	1661	4935
2	8	2.86	0.05	1661	4760
2	8	2.62	0.10	1659	4556
2	8	2.38	0.15	1658	4334
2	8	2.13	0.20	1658	4104
2	8	1.78	0.25	1662	3756
2	8	0.86	0.30	1678	2608
200v					
2	8	2.86	0.00	1604	4760
2	8	2.63	0.05	1601	4565
2	8	2.42	0.10	1600	4375
2	8	2.16	0.15	1600	4138
2	8	1.85	0.20	1603	3829
2	8	1.35	0.25	1618	3270
180v					
2	8	2.58	0.00	1525	4521
2	8	2.35	0.05	1524	4316
2	8	2.11	0.10	1524	4089
2	8	1.83	0.15	1524	3803
2	8	1.44	0.20	1531	3378
2	8	0.81	0.25	1574	2523
160v					
2	8	2.07	0.00	1373	4051
2	8	1.78	0.05	1368	3758
2	8	1.44	0.10	1370	3372
2	8	1.13	0.15	1382	2991
2	8	0.70	0.20	1442	2344
1	6	1.35	0.25	1367	1635
140v					
2	8	1.21	0.00	1115	3098
2	8	0.95	0.05	1130	2742
1	8	2.61	0.10	1168	2274
1	8	0.68	0.15	1065	1159
1	6	0.55	0.18	993	582
120v					
1	6	1.75	0.00	804	1862
1	6	1.30	0.05	779	901

Air flow rate= -2206.2-8459× Pressure+4.602× rpm

Table B.4 Fan testing report of TR16 and its air flow rate equation

# Nozzle	Size (inch)	Pressure Drop	Static pressure (Inch water)	Air flow (cfm)	rpm
2	8	0.97	0.00	1691	2758
2	8	0.88	0.05	1691	2619
2	8	0.78	0.10	1690	2472
2	8	0.67	0.15	1695	2282
1	8	1.13	0.20	1710	1489
1	8	0.88	0.25	1704	1313
1	8	0.73	0.30	1697	1191
200v					
2	8	0.90	0.00	1644	2649
2	8	0.81	0.05	1644	2519
2	8	0.72	0.10	1647	2369
2	8	0.60	0.15	1655	2167
1	8	1.01	0.20	1674	1407
1	8	0.79	0.25	1659	1244
180v					
2	8	0.85	0.00	1584	2573
2	8	0.75	0.05	1586	2424
2	8	0.66	0.10	1592	2273
2	8	0.52	0.15	1612	2006
1	8	0.87	0.20	1625	1306
1	8	0.65	0.25	1596	1123
160v					
2	8	0.67	0.00	1426	2290
2	8	0.59	0.05	1433	2139
2	8	0.50	0.10	1456	1967
1	8	0.92	0.15	1541	1343
1	8	0.58	0.20	1479	1060
1	6	0.82	0.25	1377	711
140v					
1	8	1.21	0.00	1032	1541
1	8	0.82	0.05	1229	1267
1	6	0.64	0.10	1050	628
1	4	0.51	0.12	898	248
120v					
1	4	2.00	0.00	729	493
1	4	0.85	0.02	668	320

Air flow rate= -1221.1-6323.6× Pressure+2.467× rpm

Table B.5 Fan testing report of TR12 and its air flow rate equation

# Nozzle	Size (inch)	Pressure Drop	Static pressure (Inch water)	Air flow (cfm)	rpm
1	8	1.91	0.00	1728	1936
1	8	1.75	0.05	1729	1853
1	8	1.55	0.10	1728	1744
1	8	1.31	0.15	1729	1600
1	8	1.17	0.17	1730	1515
1	6	0.92	0.20	1746	754
1	6	0.75	0.25	1743	680
1	6	0.58	0.30	1737	595
200v					
1	8	1.84	0.00	1704	1900
1	8	1.66	0.05	1705	1805
1	8	1.5	0.10	1704	1715
1	8	1.24	0.15	1706	1559
1	6	0.9	0.20	1725	745
1	6	0.7	0.25	1720	657
180v					
1	8	1.77	0.00	1676	1864
1	8	1.6	0.05	1673	1769
1	8	1.42	0.10	1675	1669
1	8	1.13	0.15	1682	1488
1	6	0.83	0.20	1707	716
1	8	0.65	0.25	1695	633
160v					
1	8	1.63	0.00	1614	1786
1	8	1.45	0.05	1610	1687
1	8	1.35	0.10	1613	1566
1	8	0.97	0.15	1642	1379
1	6	0.76	0.20	1663	682
1	6	0.57	0.25	1649	590
140v					
1	8	1.24	0.00	1431	1559
1	8	1.03	0.05	1455	1417
1	8	0.89	0.10	1494	1320
1	6	0.82	0.15	1588	711
1	6	0.51	0.25	1487	408
1	4	1.37			
120v					
1	6	1.33	0.00	993	907
1	6	0.69	0.05	1312	652
1	4	0.43	0.10	957	227

Air flow rate= -1002.1-5401.7× Pressure+1.802× rpm

The air flow rate of field measurement is determined by the equation B.1

$$\text{Air flow rate} = V \times A \quad \text{(B.1)}$$

where

V is the average air velocity (m s^{-1})

A is the traverse area of the fan (m^2)

The following table gave the fan curve method and field measurement results under specific conditions.

Table B.6 Verification results of TR12

Inlet opening	Pressure (Pa)	Air flow rate (m^3 s^{-1})		Difference
		Fan curve method	Field measurement	
100%	9.5	0.81	0.75	7.4%
50%	13.4	0.77	0.74	3.9%
25%	17.9	0.73	0.67	8.2%
0%	48.1	0.42	0.4	4.8%

Table B.7 Verification results of TR 16

Inlet opening	Pressure (Pa)	Air flow rate (m^3 s^{-1})		Difference
		Fan curve method	Field measurement	
100%	14.3	1.23	1.19	3.3%
50%	20.1	1.16	1.09	5.9%
25%	28.9	1.06	0.99	6.6%
0%	70.8	0.56	0.58	3.6%

Table B.8 Verification results of TR20

Inlet opening	Pressure (Pa)	Air flow rate (m^3 s^{-1})		Difference
		Fan curve method	Field measurement	
100%	14.3	2.25	2.09	7.1%
50%	20.1	2.16	2.00	7.5%
25%	28.9	2.02	1.87	7.4%
0%	70.8	1.35	1.25	7.4%

Table B.9 Verification results of TR24

Inlet opening	Pressure (Pa)	Air flow rate ($m^3 s^{-1}$)		Difference
		Fan curve method	Field measurement	
100%	24.8	2.91	2.71	6.8%
50%	29.0	2.85	2.61	8.4%
25%	40.0	2.70	2.59	4.1%
0%	78.0	2.17	2.06	5.1%

Table B.10 Verification results of TR36

Pressure (Pa)	Air flow rate ($m^3 s^{-1}$)		Difference
	Fan curve method	Field measurement	
24.8	5.1	4.9	4%

The above verification result indicated that the maximum flow rate difference of variable speed fan was 8.4 % less than fan curve method, while single speed fan was only 4% less of the result from fan curve method.

APPENDIX C

STATISTICAL ANALYSIS OF ODOUR AND GAS DATA

C.1 Diurnal Odour and Gas Concentration and Emission Statistical Analysis

The statistical analysis results from SPSS output for diurnal odour and gas concentrations and emissions are given in Table C.1 to C.30. Three components should be analyzed including "Room type", "Diurnal" and their interaction effect. The significance level was determined at the 5% level. If p-value of "room type" and was greater than 0.05, it denoted that there was no significant difference between nursery, farrowing and gestation in odour or gas concentration and emission. If p-value of "diurnal" effect (a function of ambient temperature, room temperature, ventilation rate, barn management) less than 0.05, it meant the odour or gas concentration and emission had significant variation in the daily course. If p-value of "room type * diurnal" larger than 0.05, it demonstrated there was no interaction effect of "room type" and "diurnal", hence the means of odour and gas concentrations or emissions from three rooms could be compared without considering their interaction.

Table C. 1 ANOVA table for odour concentrations in August

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	319894	1	319894	2.28	0.27
Roomtype	3204209	2	1602104	11.43	0.08
Roomtype * Day	280349	2	140174	0.32	0.73
Diurnal	5697195	7	813885	1.53	0.29
Diurnal * Day	3717475	7	531068	1.22	0.36
Diurnal * Roomtype	4968425	14	354887	0.82	0.65
Error	5651922	13	434763		
Corrected Total	24117944	46			

Table C. 2 ANOVA table for odour emissions in August

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	1479	1	1479	36.43	0.03
Roomtype	402	2	201	4.95	0.17
Day * Roomtype	81	2	41	0.29	0.76
Diurnal	13533	7	1933	12.25	0.00
Day * Diurnal	1105	7	158	1.11	0.41
Roomtype * Diurnal	2513	14	179	1.27	0.34
Error	1844	13	142		
Corrected Total	21204	46			

Table C. 3 ANOVA table for NH_3 concentrations in August

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	16.3	1	16.3	1.97	0.30
Roomtype	34.1	2	17.1	2.06	0.33
Day * Roomtype	16.5	2	8.3	54.50	0.00
Diurnal	121.9	7	17.4	7.17	0.01
Day * Diurnal	17.0	7	2.4	16.00	0.00
Roomtype * Diurnal	11.2	14	0.8	5.28	0.00
Error	2.1	14	0.2		
Corrected Total	219.3	47			

Table C. 4 ANOVA table for NH_3 emissions in August

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	980.1	1	980.1	0.45	0.57
Roomtype	16530.1	2	8265.1	3.80	0.21
Day * Roomtype	4347.9	2	2174.0	18.80	0.00
Diurnal	12143.4	7	1734.8	5.98	0.02
Day * Diurnal	2029.9	7	290.0	2.51	0.07
Roomtype * Diurnal	9183.4	14	656.0	5.68	0.00
Error	1617.2	14	115.5		
Corrected Total	46832.1	47			

Table C. 5 ANOVA table for H_2S concentrations in August

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	60563.0	1	60563.0	1.43	0.35
Roomtype	596863.5	2	298431.8	7.06	0.12
Day * Roomtype	84513.5	2	42256.8	6.62	0.01
Diurnal	971203.6	7	138743.4	18.28	0.00
Day * Diurnal	53141.1	7	7591.6	1.19	0.37
Roomtype * Diurnal	170394.8	14	12171.1	1.91	0.12
Error	89344.8	14	6381.8		
Corrected Total	2026024.5	47			

Table C. 6 ANOVA table for H_2S emissions in August

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	43.0	1	43.0	3.12	0.22
Roomtype	24.1	2	12.0	0.87	0.53
Day * Roomtype	27.5	2	13.8	6.61	0.01
Diurnal	140.7	7	20.1	9.56	0.00
Day * Diurnal	14.7	7	2.1	1.01	0.47
Roomtype * Diurnal	38.8	14	2.8	1.33	0.30
Error	29.2	14	2.1		
Corrected Total	318.0	47			

Table C. 7 ANOVA table for CO_2 concentrations in August

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	351063.0	1	351063.0	201.63	0.00
Roomtype	1247851.0	2	623925.5	358.34	0.00
Day * Roomtype	3482.3	2	1741.1	0.21	0.81
Diurnal	3367837.0	7	481119.6	25.08	0.00
Day * Diurnal	134282.8	7	19183.3	2.31	0.09
Roomtype * Diurnal	285649.0	14	20403.5	2.47	0.05
Error	115784.4	14	8270.3		
Corrected Total	5505949.5	47			

Table C. 8 ANOVA table for CO_2 emissions in August

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	458.7	1	458.7	22.62	0.04
Roomtype	224316.7	2	112158.3	5530.08	0.00
Day * Roomtype	40.6	2	20.3	0.03	0.97
Diurnal	19116.2	7	2730.9	14.03	0.00
Day * Diurnal	1362.8	7	194.7	0.30	0.94
Roomtype * Diurnal	11562.0	14	825.9	1.26	0.34
Error	9195.5	14	656.8		
Corrected Total	266052.4	47			

Table C. 9 ANOVA table for CH_4 concentrations in August

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	26407.6	1	26407.6	41.30	0.02
Roomtype	8133.4	2	4066.7	6.36	0.14
Day * Roomtype	1278.9	2	639.5	3.73	0.05
Diurnal	13699.6	7	1957.1	2.67	0.11
Day * Diurnal	5126.0	7	732.3	4.27	0.01
Roomtype * Diurnal	10363.8	14	740.3	4.32	0.01
Error	2227.5	14	159.1		
Corrected Total	64954.9	47			

Table C. 10 ANOVA table for CH_4 emissions in August

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	17.4	1	17.4	39.83	0.02
Roomtype	4.1	2	2.0	4.66	0.18
Day * Roomtype	0.9	2	0.4	4.33	0.04
Diurnal	27.4	7	3.9	9.39	0.00
Day * Diurnal	2.9	7	0.4	4.15	0.01
Roomtype * Diurnal	4.4	14	0.3	3.09	0.02
Error	1.3	14	0.1		
Corrected Total	59.8	47			

Table C. 11 ANOVA table for odour concentrations in February

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	6032881	1	6032881	3.99	0.18
Roomtype	51003913	2	25501957	16.88	0.06
Roomtype * Day	3021388	2	1510694	1.19	0.33
Diurnal	7274530	7	1039219	2.25	0.15
Diurnal * Day	3238564	7	462652	0.37	0.91
Diurnal * Roomtype	18631300	14	1330807	1.05	0.46
Error	17675944	14	1262567		
Corrected Total	106878519	47			

Table C. 12 ANOVA table for odour emissions in February

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	184	1	184	1.14	0.40
Roomtype	9487	2	4744	29.36	0.03
Roomtype * Day	323	2	162	3.83	0.05
Diurnal	313	7	45	1.40	0.33
Diurnal * Day	224	7	32	0.76	0.63
Diurnal * Roomtype	486	14	35	0.82	0.64
Error	590	14	42		
Corrected Total	11607	47			

Table C. 13 ANOVA table for NH_3 concentrations in February

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	5	1	5	0.34	0.62
Roomtype	819	2	409	25.75	0.04
Roomtype * Day	32	2	16	5.67	0.01
Diurnal	30	7	4	1.61	0.27
Diurnal * Day	19	7	3	0.95	0.50
Diurnal * Roomtype	85	14	6	2.16	0.08
Error	39	14	3		
Corrected Total	1029	47			

Table C. 14 ANOVA table for NH_3 emissions in February

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	32	1	32	0.04	0.87
Roomtype	86736	2	43368	49.88	0.02
Roomtype * Day	1739	2	870	8.68	0.00
Diurnal	1020	7	146	1.35	0.35
Diurnal * Day	756	7	108	1.08	0.43
Diurnal * Roomtype	1082	14	77	0.77	0.68
Error	1402	14	100		
Corrected Total	92768	47			

Table C. 15 ANOVA table for H_2S concentrations in February

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	273008	1	273008	20.91	0.04
Roomtype	13077617	2	6538808	500.74	0.00
Roomtype * Day	26117	2	13058	0.58	0.58
Diurnal	97033	7	13862	1.71	0.25
Diurnal * Day	56625	7	8089	0.35	0.91
Diurnal * Roomtype	145517	14	10394	0.46	0.92
Error	316350	14	22596		
Corrected Total	13992267	47	297708		

Table C. 16 ANOVA table for H_2S emissions in February

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	13.6	1	14	2.64	0.25
Roomtype	2553.0	2	1277	247.27	0.00
Roomtype * Day	10.3	2	5	2.31	0.14
Diurnal	24.0	7	3	2.27	0.15
Diurnal * Day	10.6	7	2	0.67	0.69
Diurnal * Roomtype	24.5	14	2	0.78	0.67
Error	31.3	14	2		
Corrected Total	2667	47	57		

Table C. 17 ANOVA table for CO_2 concentrations in February

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	69410.449	1	69410	0.46	0.57
Roomtype	6921873.355	2	3460937	22.97	0.04
Roomtype * Day	301279.9852	2	150640	2.56	0.11
Diurnal	849868.8558	7	121410	0.76	0.64
Diurnal * Day	1124551.149	7	160650	2.73	0.05
Diurnal * Roomtype	1178459.543	14	84176	1.43	0.26
Error	823077.5857	14	58791		
Corrected Total	11268521	47	239756		

Table C. 18 ANOVA table for CO_2 emissions in February

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	9.0	1	9	0.30	0.64
Roomtype	3746.1	2	1873	61.49	0.02
Roomtype * Day	60.9	2	30	6.23	0.01
Diurnal	96.4	7	14	1.03	0.49
Diurnal * Day	94.0	7	13	2.74	0.05
Diurnal * Roomtype	106.6	14	8	1.55	0.21
Error	68.5	14	5		
Corrected Total	4182	47	89		

Table C. 19 ANOVA table for CH_4 concentrations in February

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	3178.2	1	3178	3.85	0.19
Roomtype	276568.3	2	138284	167.63	0.01
Roomtype * Day	1649.9	2	825	3.39	0.06
Diurnal	5073.1	7	725	1.78	0.23
Diurnal * Day	2854.2	7	408	1.67	0.19
Diurnal * Roomtype	3947.1	14	282	1.16	0.39
Error	3398.8	14	243		
Corrected Total	296669.7	47	6312		

Table C. 20 ANOVA table for CH_4 emissions in February

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	0.01	1	0.01	3.43	0.21
Roomtype	10.11	2	5.05	1338.68	0.00
Roomtype * Day	0.01	2	0.00	2.34	0.13
Diurnal	0.04	7	0.01	1.04	0.48
Diurnal * Day	0.04	7	0.01	3.66	0.02
Diurnal * Roomtype	0.07	14	0.01	3.25	0.02
Error	0.02	14	0.00		
Corrected Total	10.31	47	0.22		

Table C. 21 ANOVA table for odour concentrations in April

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	579481	1	579481	0.20	0.70
Roomtype	36428383	2	18214191	6.39	0.14
Roomtype * Day	5696395	2	2848198	4.18	0.04
Diurnal	12806953	7	1829565	6.23	0.01
Diurnal * Day	2054403	7	293486	0.43	0.87
Diurnal * Roomtype	17039720	14	1217123	1.79	0.14
Error	9527777	14	680555		
Corrected Total	84133112	47			

Table C. 22 ANOVA table for odour emissions in April

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	38	1	38	0.04	0.86
Roomtype	31305	2	15653	16.43	0.06
Roomtype * Day	1905	2	953	2.31	0.14
Diurnal	7546	7	1078	3.87	0.05
Diurnal * Day	1948	7	278	0.67	0.69
Diurnal * Roomtype	7835	14	560	1.36	0.29
Error	5778	14	413		
Corrected Total	56354	47			

Table C. 23 ANOVA table for NH_3 concentrations in April

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	6.7	1	6.7	0.62	0.51
Roomtype	136.1	2	68.1	6.22	0.14
Roomtype * Day	21.9	2	10.9	1.94	0.18
Diurnal	67.7	7	9.7	2.04	0.18
Diurnal * Day	33.3	7	4.8	0.84	0.57
Diurnal * Roomtype	128.2	14	9.2	1.62	0.19
Error	79.1	14	5.7		
Corrected Total	473	47			

Table C. 24 ANOVA table for NH_3 emissions in April

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	157.5	1	157.5	0.51	0.55
Roomtype	26740.6	2	13370.3	43.67	0.02
Roomtype * Day	612.4	2	306.2	1.55	0.25
Diurnal	18935.3	7	2705.0	6.10	0.01
Diurnal * Day	3106.7	7	443.8	2.25	0.09
Diurnal * Roomtype	2574.0	14	183.9	0.93	0.55
Error	2766.1	14	197.6		
Corrected Total	54892.5	47	1168		

Table C. 25 ANOVA table for H_2S concentrations in April

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	32033.3	1	32033.3	7.06	0.12
Roomtype	6088254.2	2	3044127.1	670.57	0.00
Roomtype * Day	9079.2	2	4539.6	0.51	0.61
Diurnal	772991.7	7	110427.4	20.69	0.00
Diurnal * Day	37366.7	7	5338.1	0.60	0.75
Diurnal * Roomtype	678545.8	14	48467.6	5.41	0.00
Error	125520.8	14	8965.8		
Corrected Total	7743791.7	47	164762		

Table C. 26 ANOVA table for H_2S emissions in April

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	8.5	1	8.5	5.09	0.15
Roomtype	7357.7	2	3678.8	2190.20	0.00
Roomtype * Day	3.4	2	1.7	0.59	0.56
Diurnal	178.1	7	25.4	11.34	0.00
Diurnal * Day	15.7	7	2.2	0.80	0.60
Diurnal * Roomtype	145.1	14	10.4	3.69	0.01
Error	39.3	14	2.8		
Corrected Total	7747.9	47	165		

Table C. 27 ANOVA table for CO_2 concentrations in April

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	8138.0	1	8138.0	0.74	0.48
Roomtype	1209126.0	2	604563.0	55.15	0.02
Roomtype * Day	21926.0	2	10963.0	2.35	0.13
Diurnal	1458778.6	7	208396.9	8.74	0.01
Diurnal * Day	166824.5	7	23832.1	5.11	0.00
Diurnal * Roomtype	564307.3	14	40307.7	8.64	0.00
Error	65324.0	14	4666.0		
Corrected Total	3494424.5	47	74349		

Table C. 28 ANOVA table for CO_2 emissions in April

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	7.7	1	7.7	1.15	0.40
Roomtype	5337.4	2	2668.7	397.19	0.00
Roomtype * Day	13.4	2	6.7	3.09	0.08
Diurnal	505.7	7	72.2	29.47	0.00
Diurnal * Day	17.2	7	2.5	1.13	0.40
Diurnal * Roomtype	229.3	14	16.4	7.52	0.00
Error	30.5	14	2.2		
Corrected Total	6141.2	47	131		

Table C. 29 ANOVA table for CH_4 concentrations in April

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	9.6	1	9.6	0.48	0.56
Roomtype	18357.4	2	9178.7	461.10	0.00
Roomtype * Day	39.8	2	19.9	0.58	0.57
Diurnal	13544.4	7	1934.9	7.48	0.01
Diurnal * Day	1810.6	7	258.7	7.60	0.00
Diurnal * Roomtype	2975.0	14	212.5	6.24	0.00
Error	476.4	14	34.0		
Corrected Total	37213.2	47	792		

Table C. 30 ANOVA table for CH_4 emissions in April

Source	Sum of Squares	df	Mean Square	F	Sig.
Day	0.02	1	0.02	7.78	0.11
Roomtype	5.71	2	2.86	1388.73	0.00
Roomtype * Day	0.00	2	0.00	0.86	0.44
Diurnal	0.11	7	0.02	1.02	0.49
Diurnal * Day	0.11	7	0.02	6.41	0.00
Diurnal * Roomtype	0.16	14	0.01	4.73	0.00
Error	0.03	14	0.00		
Corrected Total	6.1	47	0.13		

C.2 Seasonal Odour and Gas Concentration and Emission Statistical Analysis

Due to the interaction effect of "room type' and "month" existing for all odour and gas concentration and emissions, the seasonal data were analyzed separately according to different room. Hence, we mainly focus on if the odour and gas concentration and emission varied significantly over the month. The Duncan multiple comparisons were used to compare the odour and gas concentration or emission difference between individual months. The Duncan multiple comparison results from SPSS GLM procedure are listed from C.31 to C.66. In the output table, individual month under the same subset demonstrated that there was no significant difference among months ($p>0.05$) for specific dependent variables. For example, Table C.31 is the SPSS results of multiple comparisons for odour concentration in nursery room. Month of Jul, May, Aug, Jun, and Apr under the same subset 1, which demonstrated there is no significant difference among these months.

Table C. 31 Duncan multiple comparison of odour concentration for nursery

Month	N	Subset					
		1	2	3	4	5	6
Jul	2	956					
May	2	1039.5					
Aug	2	1513.5	1513.5				
Jun	2	2048	2048	2048			
Apr	2	3265.5	3265.5	3265.5	3265.5		
Nov	2		3769.5	3769.5	3769.5	3769.5	
Mar	2			4483.5	4483.5	4483.5	
Sep	2				4618.5	4618.5	
Feb	2					5880	
Jan	2						8315.5
Dec	2						8967
Sig.		0.069106	0.07087	0.05374	0.2561	0.0883	0.5478

Table C. 32 Duncan multiple comparison of odour emission for nursery

Month	N	Subset	
		1	2
May	2	16.910888	
Jun	2	19.618692	
Nov	2	21.672196	
Jul	2	24.789533	
Sep	2	31.075	
Mar	2	31.152243	
Aug	2	32.96	
Feb	2	40.665421	40.665421
Dec	2	43.712336	43.712336
Jan	2	46.661495	46.661495
Apr	2		67.089907
Sig.		0.0519887	0.067732

Table C. 33 Duncan multiple comparison of NH_3 concentration for nursery

Month	N	Subset				
		1	2	3	4	5
Sep	2	5				
May	2	5.75	5.75			
Aug	2	6	6			
Jul	2	6.5	6.5			
Nov	2	8.5	8.5	8.5		
Apr	2		9.5	9.5		
Oct	2		9.5	9.5		
Jun	2			11		
Jan	2				16.5	
Mar	2				18.5	
Dec	2					23.5
Feb	2					26.5
Sig.		0.070369	0.05716	0.175365	0.238	0.0871

Table C. 34 Duncan multiple comparison of NH_3 emission for nursery

Month	N	Subset			
		1	2	3	4
Sep	2	23.556075			
Nov	2	34.604206			
Oct	2	43.296729			
Jan	2		66.48785		
May	2		66.703505		
Jun	2		74.815421	74.81542	
Dec	2		80.853738	80.85374	
Mar	2			90.44206	
Aug	2			90.6	
Jul	2				118.842
Feb	2				130.122
Apr	2				134.9
Sig.		0.0657135	0.1776511	0.141469	0.12598

Table C. 35 Duncan multiple comparison of H_2S concentration for nursery

Month	N	Subset					
		1	2	3	4	5	6
Aug	2	397.5					
May	2	424					
Jul	2	513					
Sep	2	645					
Jun	2		1080				
Apr	2		1150	1150			
Oct	2		1247.5	1247.5			
Mar	2			1375	1375		
Dec	2				1548.5	1548.5	
Jan	2					1650	1650
Nov	2					1750	1750
Feb	2						1850
Sig.		0.054521	0.16548	0.070137	0.1343	0.1006	0.1029

Table C. 36 Duncan multiple comparison of H_2S emission for nursery

Month	N	Subset			
		1	2	3	4
Sep	2	6.4219626			
May	2	10.41035	10.41035		
Dec	2	11.501846	11.501846	11.50185	
Oct	2	11.953738	11.953738	11.95374	
Aug	2	12.89	12.89	12.89	
Jan	2	14.165888	14.165888	14.16589	
Mar	2	14.25	14.25	14.25	
Nov	2	14.922897	14.922897	14.9229	
Jun	2		15.506075	15.50607	
Feb	2			19.19159	
Jul	2			19.68645	
Apr	2				34.528
Sig.		0.0537054	0.2195673	0.062581	1

Table C. 37 Duncan multiple comparison of CO_2 concentration for nursery

Month	N	Subset				
		1	2	3	4	5
Jul	2	890.5				
May	2	1118.5	1118.5			
Aug	2	1175	1175			
Jun	2		1436.5	1436.5		
Apr	2		1452.5	1452.5		
Sep	2			1851	1851	
Oct	2				2180	
Nov	2				2190	
Dec	2					2852.5
Jan	2					2857
Mar	2					3020
Feb	2					3238.5
Sig.		0.175723	0.12559	0.057327	0.1118	0.0811

Table C. 38 Duncan multiple comparison of CO_2 emission for nursery

Month	N	Subset	
		1	2
Jun	2	13.578645	
Sep	2	14.637869	
May	2	15.233888	
Nov	2	16.484972	
Aug	2	18.005	
Jul	2	18.116243	
Oct	2	18.490374	
Dec	2	20.32528	
Jan	2	23.589252	23.589252
Mar	2		30.250093
Apr	2		32.840748
Feb	2		32.845626
Sig.		0.0534867	0.0602105

Table C. 39 Duncan multiple comparison of CH_4 concentration for nursery

Month	N	Subset						
		1	2	3	4	5	6	7
Jul	2	19.25						
May	2	37.7	37.7					
Sep	2	43.45	43.45					
Jun	2		56.6	56.6				
Apr	2			81.85	81.85			
Mar	2				96.6			
Oct	2				100.8			
Aug	2					146.15		
Dec	2					149.3		
Nov	2					153	153	
Jan	2						184.1	
Feb	2							275.7
Sig.		0.138289	0.23915	0.107686	0.238	0.662	0.0535	1

Table C. 40 Duncan multiple comparison of CH_4 emission for nursery

Month	N	Subset		
		1	2	3
Sep	2	0.1873822		
Jul	2	0.3222603		
Jun	2	0.3525916	0.3525916	
May	2	0.3996224	0.3996224	
Oct	2	0.4183661	0.4183661	
Mar	2	0.4342729	0.4342729	
Dec	2	0.4807995	0.4807995	
Nov	2	0.5669579	0.5669579	
Jan	2	0.6903759	0.6903759	
Apr	2	1.0597308	1.0597308	
Feb	2		1.2393617	
Aug	2			2.18
Sig.		0.0548513	0.0510386	1

Table C. 41 Duncan multiple comparison of dust concentration for nursery

Month	N	Subset		
		1	2	3
Sep	2	1.025		
Jul	2	1.03		
Aug	2	1.0625		
Dec	2	1.095		
Oct	2	2.14	2.14	
Nov	2	2.57	2.57	2.57
May	2	2.59	2.59	2.59
Jan	2	2.6	2.6	2.6
Jun	2		3.335	3.335
Feb	2		3.36	3.36
Mar	2		3.75	3.75
Apr	2			4.44
Sig.		0.133437	0.12468	0.079775

Table C. 42 Duncan multiple comparison of dust deposition for nursery

Month	N	Subset		
		1	2	3
Sep	2	23.315		
Aug	2	35.72	35.72	
Nov	2	37.465	37.465	
May	2	56.705	56.705	56.705
Dec	2	69.865	69.865	69.865
Oct	2	72.035	72.035	72.035
Jun	2		76.94	76.94
Jul	2		81.185	81.185
Jan	2			89.13
Mar	2			99.92
Feb	2			101.185
Apr	2			104.98
Sig.		0.0523924	0.0694461	0.057987

Table C. 43 Duncan multiple comparison of odour concentration for farrowing

Month	N	Subset				
		1	2	3	4	5
May	2	367				
Jul	2	538				
Apr	2	1373	1373			
Jun	2	1960	1960	1960		
Aug	2		2214	2214	2214	
Feb	2		2242	2242	2241.5	
Nov	2			3496	3495.5	3495.5
Dec	2				3770	3770
Mar	2					4157.5
Sep	2					4157.5
Jan	2					4871
Sig.		0.0509	0.258	0.058	0.0556	0.0898

Table C. 44 Duncan multiple comparison of odour emission for farrowing

Month	N	Subset		
		1	2	3
May	2	2.99093		
Feb	2	10.8593	10.859	
Nov	2	12.5493	12.549	12.5493
Jul	2	14.5059	14.506	14.5059
Jun	2	16.1824	16.182	16.1824
Apr	2	18.2625	18.263	18.2625
Jan	2	18.6646	18.665	18.6646
Dec	2	18.9566	18.957	18.9566
Mar	2	20.3771	20.377	20.3771
Sep	2		26.81	26.81
Aug	2			32.16
Sig.		0.07821	0.1016	0.05161

Table C. 45 Duncan multiple comparison of NH_3 concentration for farrowing

Month	N	Subset				
		1	2	3	4	5
Jul	2	3				
Aug	2	4.5				
May	2	4.5				
Apr	2		8			
Jan	2		10	10		
Nov	2			12.5	12.5	
Dec	2			13	13	
Sep	2			13	13	
Jun	2				13.5	13.5
Oct	2				14	14
Feb	2				15	15
Mar	2					16.5
Sig.		0.3377	0.187	0.075	0.1395	0.0748

Table C. 46 Duncan multiple comparison of NH_3 emission for farrowing

Month	N	Subset				
		1	2	3	4	5
May	2	25.9117				
Jan	2	27.2056				
Nov	2	31.95	31.95			
Aug	2	40	40	40		
Oct	2	41.0075	41.007	41.0075		
Dec	2	46.15	46.15	46.15	46.15	
Feb	2	49.2355	49.236	49.2355	49.23551	49.2355
Mar	2	56.2028	56.203	56.2028	56.2028	56.2028
Jul	2		58.26	58.2598	58.25981	58.2598
Sep	2			68.3458	68.34579	68.3458
Jun	2				75.44579	75.4458
Apr	2					77.2374
Sig.		0.05142	0.0829	0.06433	0.05535	0.06534

Table C. 47 Duncan multiple comparison of H_2S concentration for farrowing

Month	N	Subset				
		1	2	3	4	5
Jul	2	223.5				
May	2	246.5				
Apr	2	495	495			
Mar	2	510	510	510		
Sep	2		565	565		
Dec	2		605	605		
Feb	2		620	620		
Aug	2		670	670		
Jun	2			824.5	824.5	
Oct	2				1094.5	1094.5
Jan	2					1150
Nov	2					1150
Sig.		0.0646	0.249	0.051	0.0615	0.6941

Table C. 48 Duncan multiple comparison of H_2S emission for farrowing

Month	N	Subset				
		1	2	3	4	5
May	2	3.04689				
Mar	2	3.6743	3.6743			
Feb	2	4.19369	4.1937			
Dec	2	4.54977	4.5498			
Sep	2	6.19766	6.1977	6.19766		
Nov	2	6.20327	6.2033	6.20327		
Jan	2	6.57477	6.5748	6.57477		
Oct	2		6.9739	6.97395	6.973949	
Jul	2			8.96299	8.962991	
Jun	2			9.63673	9.636729	9.63673
Apr	2				10.1229	10.1229
Aug	2					12.7
Sig.		0.05167	0.0661	0.05519	0.06863	0.06885

Table C. 49 Duncan multiple comparison of CO_2 concentration for farrowing

Month	N	Subset						
		1	2	3	4	5	6	7
Jul	2	704						
May	2	945	945					
Aug	2		1100	1100				
Apr	2		1209	1209				
Jun	2			1410	1409.5			
Sep	2				1738.5	1738.5		
Oct	2					1925	1925	
Nov	2					1977.5	1978	
Feb	2					2036	2036	
Mar	2						2200	
Jan	2							2647
Dec	2							2678
Sig.		0.184	0.168	0.11	0.0783	0.1322	0.16	0.859

Table C. 50 Duncan multiple comparison of CO_2 emission for farrowing

Month	N	Subset			
		1	2	3	4
May	2	4.94411			
Nov	2	9.03718	9.0372		
Aug	2	9.05	9.05		
Jul	2	9.83969	9.8397		
Oct	2	10.0951	10.095	10.0951	
Jun	2	10.8019	10.802	10.8019	
Feb	2		12.799	12.799	12.79901
Mar	2		13.831	13.8308	13.83081
Jan	2		13.973	13.9734	13.97338
Sep	2		14.737	14.7372	14.73721
Apr	2			16.4293	16.42929
Dec	2				18.61864
Sig.		0.06773	0.0785	0.05235	0.069301

Table C. 51 Duncan multiple comparison of CH_4 concentration for farrowing

Month	N	Subset							
		1	2	3	4	5	6	7	8
Jul	2	16.1							
May	2	39.95	39.95						
Sep	2		54.25	54.25					
Apr	2			74.9	74.9				
Dec	2			81.5	81.5	81.5			
Mar	2				100.5	100.5	101		
Jan	2					111.85	112	111.9	
Oct	2						116	116	
Jun	2						125	125.3	
Feb	2							139.4	
Nov	2							141	
Aug	2								180
Sig.		0.1207	0.336	0.094	0.1131	0.0652	0.13	0.087	1

Table C. 52 Duncan multiple comparison of CH_4 emission for farrowing

Month	N	Subset	
		1	2
May	2	0.208987	
Sep	2	0.261385	
Dec	2	0.264173	
Jan	2	0.279476	
Jul	2	0.282392	
Mar	2	0.314949	
Oct	2	0.324089	
Nov	2	0.32965	
Feb	2	0.398538	
Jun	2	0.643804	
Apr	2	0.659443	
Aug	2		1.76
Sig.		0.261898	1

Table C. 53 Duncan multiple comparison of dust concentration for farrowing

Month	N	Subset	
		1	2
Jul	2	0.18	
Sep	2	0.19	
Aug	2	0.1925	
Jun	2	0.285	
May	2	0.365	
Dec	2	0.51	
Oct	2	0.55	
Apr	2	0.56	
Jan	2	0.58	
Nov	2	0.63	
Mar	2		1.14
Feb	2		1.395
Sig.		0.078	0.242

Table C. 54 Duncan multiple comparison of dust deposition for farrowing

Month	N	Subset			
		1	2	3	4
Aug	2	6.365			
Jul	2	7.74			
Sep	2	8.66			
Jun	2	11.03	11.03		
Nov	2	12.365	12.365		
Oct	2	12.71	12.71		
May	2	14.365	14.365	14.365	
Dec	2	14.75	14.75	14.75	
Apr	2		19.455	19.455	19.455
Jan	2		21.34	21.34	21.34
Mar	2			23.645	23.645
Feb	2				25.69
Sig.		0.10892	0.0542	0.07384	0.206395

Table C. 55 Duncan multiple comparison of odour concentration for gestation

Month	N	Subset			
		1	2	3	4
Jul	2	400			
May	2	512			
Nov	2	1038.5			
Apr	2	1218			
Aug	2	1236			
Sep	2		2078.5		
Mar	2		2241.5	2241.5	
Dec	2			2939.5	
Jan	2				3770
Feb	2				4096
Sig.		0.05127	0.6486	0.07201	0.3697

Table C. 56 Duncan multiple comparison of odour emission for gestation

Month	N	Subset	
		1	2
Nov	2	3.22088	
Feb	2	5.2953	
Mar	2	6.305	
Jan	2	7.92397	
Dec	2	10.7688	
May	2	10.7901	
Apr	2	11.3675	
Sep	2	13.4	
Jul	2	16.791	
Aug	2		47.2
Sig.		0.12091	1

Table C. 57 Duncan multiple comparison of NH_3 concentration for gestation

Month	N	Subset				
		1	2	3	4	5
Jul	2	3				
May	2	4	4			
Aug	2	5.5	5.5			
Jun	2		6			
Sep	2			12.5		
Apr	2			14.5	14.5	
Oct	2				15.5	
Nov	2				16	
Feb	2					19.5
Mar	2					20
Dec	2					20.5
Jan	2					20.5
Sig.		0.0859	0.1608	0.14264	0.2848	0.481

Table C. 58 Duncan multiple comparison of NH_3 emission for gestation

Month	N	Subset			
		1	2	3	4
Feb	2	17.8548			
Jan	2	29.6322			
Nov	2	36.3257	36.33		
Jun	2	39.2051	39.21		
Mar	2	40.0308	40.03	40.0308	
Dec	2	51.3011	51.3	51.3011	
Oct	2	52.0974	52.1	52.0974	
May	2	58.2166	58.22	58.2166	
Sep	2	60.6476	60.65	60.6476	
Jul	2		91.42	91.4198	
Apr	2			96.5416	96.542
Aug	2				147.25
Sig.		0.12757	0.057	0.05099	0.0507

Table C. 59 Duncan multiple comparison of H_2S concentration for gestation

Month	N	Subset					
		1	2	3	4	5	6
May	2	122.5					
Jul	2	163	163				
Aug	2		247.5	247.5			
Jun	2			263			
Oct	2			335	335		
Sep	2			335	335		
Nov	2				375	375	
Jan	2				380	380	
Dec	2				388	388	
Mar	2					457.5	457.5
Apr	2					460	460
Feb	2						510
Sig.		0.36425	0.0727	0.08272	0.2812	0.096	0.2673

Table C. 60 Duncan multiple comparison of H_2S emission for gestation

Month	N	Subset			
		1	2	3	4
Feb	2	0.98341			
Jan	2	1.17149			
Nov	2	1.74386			
Mar	2	1.93853			
Dec	2	2.12727			
Oct	2	2.39168			
Sep	2	3.44362	3.4436		
Jun	2	3.63032	3.6303		
May	2	3.84652	3.8465		
Apr	2		6.4527		
Jul	2			10.1066	
Aug	2				13.86
Sig.		0.08679	0.0632	1	1

Table C. 61 Duncan multiple comparison of CO_2 concentration for gestation

Month	N	Subset						
		1	2	3	4	5	6	7
Jul	2	795						
Aug	2	970	970					
May	2	1099.5	1099.5	1099.5				
Jun	2	1221	1221	1221				
Apr	2		1514	1514	1514			
Sep	2			1732	1732	1732		
Oct	2				2010	2010	2010	
Nov	2					2280	2280	
Feb	2						2436	
Mar	2						2518	
Dec	2							3350
Jan	2							3577
Sig.		0.18515	0.0975	0.05838	0.1184	0.088	0.1193	0.4351

Table C. 62 Duncan multiple comparison of CO_2 emission for gestation

Month	N	Subset		
		1	2	3
Feb	2	4.40677		
Jun	2	9.46733	9.4673	
Mar	2	9.81238	9.8124	
Nov	2	9.87397	9.874	
Jan	2	11.102	11.102	
Oct	2	13.0782	13.078	13.0782
Sep	2	13.6103	13.61	13.6103
Apr	2		16.403	16.4031
Dec	2		17.513	17.5133
Aug	2		17.7	17.7
May	2		18.996	18.9956
Jul	2			22.2901
Sig.		0.06144	0.0566	0.06124

Table C. 63 Duncan multiple comparison of CH_4 concentration for gestation

Month	N	Subset						
		1	2	3	4	5	6	7
Jul	2	10.5						
Sep	2	13.6						
May	2	14						
Jun	2		21.35					
Oct	2			29.6				
Dec	2				37.55			
Nov	2				38.25			
Jan	2				42.7	42.7		
Apr	2				42.85	42.85		
Mar	2					44.9		
Feb	2						74.7	
Aug	2							128.7
Sig.		0.17163	1	1	0.0527	0.379	1	1

Table C. 64 Duncan multiple comparison of CH_4 emissions for gestation

Month	N	Subset				
		1	2	3	4	5
Jan	2	0.05665				
Sep	2	0.0609				
Feb	2	0.06246				
Nov	2	0.0801	0.0801			
Mar	2	0.08238	0.0824			
Dec	2	0.0873	0.0873			
Oct	2	0.0919	0.0919			
Jun	2		0.1277			
May	2			0.19193		
Apr	2				0.25996	
Jul	2				0.286129	
Aug	2					3.73
Sig.		0.15626	0.0601	1	0.235886	1

Table C. 65 Duncan multiple comparison of dust concentration for gestation

Month	N	Subset		
		1	2	3
Jul	2	0.26		
Jan	2	0.43	0.43	
Aug	2	0.5575	0.5575	
Jun	2	0.615	0.615	
May	2	0.625	0.625	
Apr	2	0.65	0.65	0.65
Sep	2	0.86	0.86	0.86
Dec	2	1.03	1.03	1.03
Oct	2	1.03	1.03	1.03
Mar	2	1.045	1.045	1.045
Feb	2		1.215	1.215
Nov	2			1.4825
Sig.		0.06774	0.0677	0.05243

Table C. 66 Duncan multiple comparison of dust deposition for gestation

Month	N	Subset		
		1	2	3
Jul	2	13.985		
Aug	2	14.865	14.865	
Sep	2	18.07	18.07	18.07
May	2	18.445	18.445	18.445
Jun	2	19.025	19.025	19.025
Oct	2	19.805	19.805	19.805
Apr	2	20.555	20.555	20.555
Dec	2	23.18	23.18	23.18
Jan	2		31.17	31.17
Mar	2			33.22
Nov	2			33.225
Feb	2			33.89
Sig.		0.25439	0.0578	0.06581

APPENDIX D

CR10X DATA LOGGER PROGRAMMING

```
;{CR10X}
;This program is designed for measuring temperature, humidity, pressure., fan speed of nursery room and farrowing as well as concentration of ammonia and carbon dioxide.
; Developed by: Yuanyuan Wang
*Table 1 Program
 01: 1        Execution Interval (seconds)
1:  Do (P86)
 1: 10       Set Output Flag High (Flag 0)
; Identify the subroutine for each index
2:  If (X<=>F) (P89)
 1: 1        X Loc [ Index     ]
 2: 1        =
 3: 0        F
 4: 1        Call Subroutine 1
3:  If (X<=>F) (P89)
 1: 1        X Loc [ Index     ]
 2: 1        =
 3: 1        F
 4: 2        Call Subroutine 2
4:  If (X<=>F) (P89)
 1: 1        X Loc [ Index     ]
 2: 1        =
 3: 2        F
 4: 3        Call Subroutine 3
*Table 2 Program
 02:  0.0000        Execution Interval (seconds)
*Table 3 Subroutines
;*****************************
1:  Beginning of Subroutine (P85)
 1: 1        Subroutine 1
;Set Port 4 high to measure Nursery Room for 5 minutes while measuring
;Fan speed, RH and Temp
2:  Set Port(s) (P20)
 1: 9900     C8..C5 = nc/nc/low/low
 2: 1999     C4..C1 = high/nc/nc/nc
3:  Timer (P26)
 1: 2        Loc [ Timer     ]
4:  If (X<=>F) (P89)
 1: 2        X Loc [ Timer     ]
 2: 3        >=
 3: 300      F
 4: 30       Then Do
5:  Z=F (P30)
 1: 1        F
 2: 00       Exponent of 10
 3: 1        Z Loc [ Index     ]
6:  Timer (P26)
```

```
 1: 0       Reset Timer
7:  Do (P86)
1: 4       Call Subroutine 4
8:  Else (P94)
9:  Do (P86)
 1: 4       Call Subroutine 4
10:  End (P95)
11:  End (P95)
;*****************************
12:  Beginning of Subroutine (P85)
 1: 2       Subroutine 2
;Set Port 5 high to measure Farrow
Room for 5 minutes while measuring
;Fan speed, RH and Temp
13:  Set Port(s) (P20)
 1: 9901     C8..C5 = nc/nc/low/high
 2: 0999     C4..C1 = low/nc/nc/nc
14:  Timer (P26)
 1: 2       Loc [ Timer     ]
15:  If (X<=>F) (P89)
 1: 2       X Loc [ Timer     ]
 2: 3       >=
 3: 300      F
 4: 30       Then Do
16:  Z=F (P30)
 1: 2       F
 2: 00       Exponent of 10
 3: 1       Z Loc [ Index     ]
17:  Timer (P26)
 1: 0       Reset Timer
18:  Do (P86)
 1: 4       Call Subroutine 4
19:  Else (P94)
20:  Do (P86)
 1: 4       Call Subroutine 4
21:  End (P95)
22:  End (P95)
;*****************************
23:  Beginning of Subroutine (P85)
 1: 3       Subroutine 3
;Set Port 6 high to measure Breeding
Room for 5 minutes while measuring
;Fan speed, RH and Temp
24:  Set Port(s) (P20)
 1: 9910     C8..C5 = nc/nc/high/low
 2: 0999     C4..C1 = low/nc/nc/nc
25:  Timer (P26)
 1: 2       Loc [ Timer     ]
26:  If (X<=>F) (P89)
 1: 2       X Loc [ Timer     ]
 2: 3       >=
 3: 300      F
 4: 30       Then Do
27:  Z=F (P30)
 1: 0       F
 2: 00       Exponent of 10
 3: 1       Z Loc [ Index     ]
28:  Timer (P26)
 1: 0000     Reset Timer
29:  Do (P86)
 1: 4       Call Subroutine 4
30:  Else (P94)
```

```
31:  Do (P86)
 1: 4        Call Subroutine 4
32:  End (P95)
33:  End (P95)
;*****************************
34:  Beginning of Subroutine (P85)
 1: 4        Subroutine 4
;read nursery temperature and convert it,SE1
35:  Volt (SE) (P1)
 1: 1        Reps
 2: 25       2500 mV 60 Hz Rejection Range
 3: 01       SE Channel
 4: 3        Loc [ TempNur   ]
 5: 1.0      Mult
 6: 0.0      Offset
;read nursery RH and convert it,SE2
36:  Volt (SE) (P1)
 1: 1        Reps
 2: 25       2500 mV 60 Hz Rejection Range
 3: 02       SE Channel
 4: 4        Loc [ RHNur     ]
 5: 1.0      Mult
 6: 0.0      Offset
;read the temperature of farrow room and convert it,SE3
37:  Volt (SE) (P1)
 1: 1        Reps
 2: 25       2500 mV 60 Hz Rejection Range
 3: 3        SE Channel
 4: 5        Loc [ TempFarr  ]
 5: 1.0      Mult
 6: 0.0      Offset
;read RH of farrowing room and convert it,SE4
38:  Volt (SE) (P1)
 1: 1        Reps
 2: 25       2500 mV 60 Hz Rejection Range
 3: 4        SE Channel
 4: 6        Loc [ RHFarr    ]
 5: 1.0      Mult
 6: 0.0      Offset
;read the pressure difference of nursery and farrow room, channel SE7,SE8
39:  Volt (SE) (P1)
 1: 1        Reps
 2: 25       2500 mV 60 Hz Rejection Range
 3: 7        SE Channel
 4: 7        Loc [ PreNur    ]
 5: 1.0      Mult
 6: 0.0      Offset
40:  Volt (SE) (P1)
 1: 1        Reps
 2: 25       2500 mV 60 Hz Rejection Range
 3: 8        SE Channel
```

```
 4: 8       Loc [ PreFarr   ]
 5: 1.0     Mult
 6: 0.0     Offset
;read voltage of ammonia and CO2
41:  If (X<=>F) (P89)
 1: 2       X Loc [ Timer     ]
 2: 3       >=
 3: 180     F
 4: 79      Call Subroutine 79
;read Fan speed from Multiplexer
42:  If (X<=>F) (P89)
 1: 9       X Loc [ multcount ]
 2: 1       =
 3: 4       F
 4: 9       Call Subroutine 9
43:  If (X<=>F) (P89)
 1: 9       X Loc [ multcount ]
 2: 1       =
 3: 3       F
 4: 8       Call Subroutine 8
44:  If (X<=>F) (P89)
 1: 9       X Loc [ multcount ]
 2: 1       =
 3: 2       F
 4: 7       Call Subroutine 7

45:  If (X<=>F) (P89)
 1: 9       X Loc [ multcount ]
 2: 1       =
 3: 1       F
 4: 6       Call Subroutine 6
46:  If (X<=>F) (P89)
 1: 9       X Loc [ multcount ]
 2: 1       =
 3: 0       F
 4: 5       Call Subroutine 5
47:  End (P95)
;******************************
48:  Beginning of Subroutine (P85)
 1: 5       Subroutine 5
;Set Port 1 high for first fan measurement
49:  Set Port(s) (P20)
 1: 9999    C8..C5 = nc/nc/nc/nc
 2: 9001    C4..C1 = nc/low/low/high
;Read voltage from Multiplexer and convert to RPM
50:  Excite-Delay (SE) (P4)
 1: 1       Reps
 2: 25      2500 mV 60 Hz Rejection Range (Delay must be zero)
 3: 09      SE Channel
 4: 3       Excite all reps w/Exchan 3
 5: 900     Delay (units 0.01 sec)
 6: 250     mV Excitation
 7: 17      Loc [ delay_1   ]
 8: 1.0     Mult
 9: 0.0     Offset
51:  Volt (SE) (P1)
 1: 1       Reps
 2: 25      2500 mV 60 Hz Rejection Range
```

```
 3: 9       SE Channel
 4: 12      Loc [ RPM_1    ]
 5: 0.8116  Mult
 6: -9.234  Offset
52:  Z=Z+1 (P32)
 1: 9       Z Loc [ multcount ]
53:  Real Time (P77)
 1:1111
Year,Day,Hour/Minute,Seconds
(midnight = 0000)
54:  Sample (P70)
 1: 16      Reps
 2: 1       Loc [ Index    ]
55:  Do (P86)
 1: 0    Go to end of Program Table

56:  End (P95)
;*****************************
57:  Beginning of Subroutine (P85)
 1: 6       Subroutine 6
;Set Port 2 high for second fan
measurement
58:  Set Port(s) (P20)
 1: 9999    C8..C5 = nc/nc/nc/nc
 2: 9010    C4..C1 = nc/low/high/low
;Read voltage from Multiplexer and
convert to RPM
59:  Excite-Delay (SE) (P4)
 1: 1       Reps
 2: 25          2500 mV 60 Hz Rejection
Range (Delay must be zero)
 3: 09      SE Channel
 4: 3       Excite all reps w/Exchan 3
 5: 900     Delay (units 0.01 sec)
 6: 250     mV Excitation
 7: 18      Loc [ delay_2   ]
 8: 1.0     Mult
 9: 0.0     Offset
60:  Volt (SE) (P1)
 1: 1       Reps
 2:  25     2500 mV 60 Hz Rejection
Range
 3: 9       SE Channel
 4: 13      Loc [ RPM_2    ]
 5: 0.8116  Mult
 6: -9.234  Offset
61:  Z=Z+1 (P32)
 1: 9       Z Loc [ multcount ]
62:  Real Time (P77)
 1:1111
Year,Day,Hour/Minute,Seconds
(midnight = 0000)
63:  Sample (P70)
 1: 16      Reps
 2: 1       Loc [ Index    ]
64:  Do (P86)
 1: 0       Go to end of Program Table
65:  End (P95)
;*****************************
66:  Beginning of Subroutine (P85)
 1: 7       Subroutine 7
```

;Set Port 1&2 high for third fan measurement
67: Set Port(s) (P20)
1: 9999 C8..C5 = nc/nc/nc/nc
2: 9011 C4..C1 = nc/low/high/high
;Read voltage from Multiplexer and convert to RPM

68: Excite-Delay (SE) (P4)
1: 1 Reps
2: 25 2500 mV 60 Hz Rejection Range (Delay must be zero)
3: 09 SE Channel
4: 3 Excite all reps w/Exchan 3
5: 900 Delay (units 0.01 sec)
6: 250 mV Excitation
7: 19 Loc [delay_3]
8: 1.0 Mult
9: 0.0 Offset
69: Volt (SE) (P1)
1: 1 Reps
2: 25 2500 mV 60 Hz Rejection Range
3: 9 SE Channel
4: 14 Loc [RPM_3]
5: 0.8116 Mult
6: -9.234 Offset
70: Z=Z+1 (P32)
1: 9 Z Loc [multcount]
71: Real Time (P77)
1: 1111 Year,Day,Hour/Minute,Seconds (midnight = 0000)
72: Sample (P70)
1: 16 Reps
2: 1 Loc [Index]
73: Do (P86)
1: 0 Go to end of Program Table
74: End (P95)
;*****
75: Beginning of Subroutine (P85)
1: 8 Subroutine 8
;Set Port 3 high for fourth fan measurement
76: Set Port(s) (P20)
1: 9999 C8..C5 = nc/nc/nc/nc
2: 9100 C4..C1 = nc/high/low/low
;Read voltage from Multiplexer and convert to RPM
77: Excite-Delay (SE) (P4)
1: 1 Reps
2: 25 2500 mV 60 Hz Rejection Range (Delay must be zero)
3: 09 SE Channel
4: 3 Excite all reps w/Exchan 3
5: 900 Delay (units 0.01 sec)
6: 250 mV Excitation
7: 20 Loc [delay_4]
8: 1.0 Mult
9: 0.0 Offset

```
78:  Volt (SE) (P1)
 1: 1       Reps
 2: 25      2500 mV 60 Hz Rejection Range
 3: 9       SE Channel
 4: 15      Loc [ RPM_4     ]
 5: 0.8116  Mult
 6: -9.234  Offset
79:  Z=Z+1 (P32)
 1: 9       Z Loc [ multcount ]
80:  Real Time (P77)
 1:                                 1111 Year,Day,Hour/Minute,Seconds (midnight = 0000)
81:  Sample (P70)
 1: 16      Reps
 2: 1       Loc [ Index     ]
82:  Do (P86)
 1: 0       Go to end of Program Table
83:  End (P95)
;*****************************
84:  Beginning of Subroutine (P85)
 1: 9       Subroutine 9
;Set Port 1&3 high for fifth fan measurement
85:  Set Port(s) (P20)
 1: 9999    C8..C5 = nc/nc/nc/nc
 2: 9101    C4..C1 = nc/high/low/high
;Read voltage from Multiplexer and convert to RPM
86:  Excite-Delay (SE) (P4)
 1: 1       Reps
 2: 25      2500 mV 60 Hz Rejection Range (Delay must be zero)
 3: 09      SE Channel
 4: 3       Excite all reps w/Exchan 3
 5: 900     Delay (units 0.01 sec)
 6: 250     mV Excitation
 7: 21      Loc [ delay_5   ]
 8: 1.0     Mult
 9: 0.0     Offset
87:  Volt (SE) (P1)
 1: 1       Reps
 2: 25      2500 mV 60 Hz Rejection Range
 3: 9       SE Channel
 4: 16      Loc [ RPM_5     ]
 5: 0.8116  Mult
 6: -9.234  Offset
88:  If (X<=>F) (P89)
 1: 9       X Loc [ multcount ]
 2: 1       =
 3: 4       F
 4: 30      Then Do
89:  Z=F (P30)
 1: 0       F
 2: 00      Exponent of 10
 3: 9       Z Loc [ multcount ]
90:  Real Time (P77)
 1:                                 1111 Year,Day,Hour/Minute,Seconds (midnight = 0000)
```

```
91:  Sample (P70)
 1: 16       Reps
 2: 1        Loc [ Index     ]
92:  Do (P86)
 1: 0        Go to end of Program Table
93:  Else (P94)
94:  Real Time (P77)
 1:                                  1111
Year,Day,Hour/Minute,Seconds
(midnight = 0000)
95:  Sample (P70)
 1: 16       Reps
 2: 1        Loc [ Index     ]
96:  Do (P86)
 1: 0        Go to end of Program Table
97:  End (P95)
98:  End (P95)
;*****************************
99:  Beginning of Subroutine (P85)
 1: 79       Subroutine 79
;measure Ammonia
100:  Volt (SE) (P1)
 1: 1        Reps
 2: 25          2500 mV 60 Hz Rejection
Range
 3: 10       SE Channel
 4: 10       Loc [ NH3       ]
 5: 0.2457   Mult
 6: -244.85  Offset
;measure Carbon Dioxide
101:  Volt (SE) (P1)
 1: 1        Reps
 2: 25          2500 mV 60 Hz Rejection
Range
 3: 11       SE Channel
 4: 11       Loc [ CO2 ]
 5: 1.8673   Mult
 6: -715.53  Offset
102:  End (P95)
```

```
{CR10}
; The program is designed to record the data of fan speed, humidity, temperature, pressure difference from gestation room
; Developer: Yuanyuan Wang

*Table 1 Program
  01: 1        Execution Interval (seconds)
1:  Do (P86)
  1: 10       Set Output Flag High
;*****************************
;Read voltage level of temperature and humidity value in two different locations of breeding room
; location one
2:  Volt (SE) (P1)
  1: 1        Reps
  2: 25         2500 mV 60 Hz Rejection Range
  3: 01       SE Channel
  4: 1        Loc [ TCB1      ]
  5: 1.0      Mult
  6: 0.0      Offset
3:  Volt (SE) (P1)
  1: 1        Reps
  2: 25         2500 mV 60 Hz Rejection Range
  3: 02       SE Channel
  4: 2        Loc [ RHB1      ]
  5: 1.0      Mult
  6: 0.0      Offset
;*****************************
;location two
4:  Volt (SE) (P1)
  1: 1        Reps
  2: 25         2500 mV 60 Hz Rejection Range
  3: 3        SE Channel
  4: 3        Loc [ TCB2      ]
  5: 1.0      Mult
  6: 0.0      Offset
5:  Volt (SE) (P1)
  1: 1        Reps
  2: 25         2500 mV 60 Hz Rejection Range
  3: 4        SE Channel
  4: 4        Loc [ RHB2      ]
  5: 1.0      Mult
  6: 0.0      Offset
;*****************************
;Read outside temperature
6:  Volt (SE) (P1)
  1: 1        Reps
  2: 25         2500 mV 60 Hz Rejection Range
  3: 7        SE Channel
  4: 5        Loc [ TCO1      ]
  5: 1.0      Mult
  6: 0.0      Offset
;*****************************
; read 2 pressure difference transducer
```

```
7:  Volt (SE) (P1)
 1: 1       Reps
 2: 25      2500 mV 60 Hz Rejection Range
 3: 9       SE Channel
 4: 6       Loc [ PB1      ]
 5: 1.0     Mult
 6: 0.0     Offset
8:  Volt (SE) (P1)
 1: 1       Reps
 2: 25      2500 mV 60 Hz Rejection Range
 3: 10      SE Channel
 4: 7       Loc [ PB2      ]
 5: 1.0     Mult
 6: 0.0     Offset
;*******************************
;Read fan speed from 2 digital multiplexers
; Set count=0
; Count= Count +1
; if count=1 ,call sub 1
; if count=2 ,call sub 2
; if count=3, call sub 3
; if count=4, call sub 4
; if count=5, call sub 5
; fan speed measurement output location in chanal 11,12
;       chanals C1(A),C2(B),C3(C), SE11,SE12
9:  Z=F (P30)
 1: 0       F
 2: 0       Exponent of 10
 3: 18      Z Loc [ COUNTER   ]
10:  Beginning of Loop (P87)
 1: 0       Delay
 2: 5       Loop Count
11:  Z=Z+1 (P32)
 1: 18      Z Loc [ COUNTER   ]
12:  If (X<=>F) (P89)
 1: 18      X Loc [ COUNTER   ]
 2: 1       =
 3: 1       F
 4: 1       Call Subroutine 1
13:  If (X<=>F) (P89)
 1: 18      X Loc [ COUNTER   ]
 2: 1       =
 3: 2       F
 4: 2       Call Subroutine 2
14:  If (X<=>F) (P89)
 1: 18      X Loc [ COUNTER   ]
 2: 1       =
 3: 3       F
 4: 3       Call Subroutine 3
15:  If (X<=>F) (P89)
 1: 18      X Loc [ COUNTER   ]
 2: 1       =
 3: 4       F
 4: 4       Call Subroutine 4
16:  If (X<=>F) (P89)
```

```
 1: 18      X Loc [ COUNTER   ]
 2: 1       =
 3: 5       F
 4: 5       Call Subroutine 5
17:  Step Loop Index (P90)
 1: 2       Step
18:  Excite-Delay (SE) (P4)
 1: 2       Reps
 2: 25          2500 mV 60 Hz Rejection
Range (Delay must be zero)
 3: 11      SE Channel
 4: 3       Excite all reps w/Exchan 3
 5: 400     Delay (units 0.01 sec)
 6: 250     mV Excitation
 7: 19      Loc [ delay_1   ]
 8: 1.0     Mult
 9: 0.0     Offset
19:  Volt (SE) (P1)
 1: 2       Reps
 2: 25          2500 mV 60 Hz Rejection
Range
 3: 11      SE Channel
 4: 8    -- Loc [ RPM_1    ]
 5: 1.0     Mult
 6: 0.0     Offset

20:  End (P95)
21:  Real Time (P77)
 1:                                  1111
Year,Day,Hour/Minute,Seconds
(midnight = 0000)
22:  Sample (P70)
 1: 17      Reps
 2: 1       Loc [ TCB1      ]
*Table 2 Program
 02:   0.0000          Execution   Interval
(seconds)
*Table 3 Subroutines
; Select channel 1
; set ports A(C1)high
1:  Beginning of Subroutine (P85)
 1: 1       Subroutine 1
2:  Set Port(s) (P20)
 1: 0000    C8,C7,C6,C5 Options
 2: 0001    C4..C1 = low/low/low/high
3:  End (P95)
;Select channel 1
; Set port B (C2)high
4:  Beginning of Subroutine (P85)
 1: 2       Subroutine 2
5:  Set Port(s) (P20)
 1: 0000    C8,C7,C6,C5 Options
 2: 0010    C4..C1 = low/low/high/low
6:  End (P95)
;Select channel 3
;Set port A&B high
7:  Beginning of Subroutine (P85)
 1: 3       Subroutine 3
8:  Set Port(s) (P20)
 1: 0000    C8..C5 = low/low/low/low
 2: 0011    C4..C1 = low/low/high/high
9:  End (P95)
```

;Select channel 4

;set port C(C3)high

10: Beginning of Subroutine (P85)

 1: 4   Subroutine 4

11: Set Port(s) (P20)

 1: 0000   C8..C5 = low/low/low/low

 2: 0100   C4..C1 = low/high/low/low

12: End (P95)

;Select channel 4

;set port A & C high

13: Beginning of Subroutine (P85)

 1: 5   Subroutine 5

14: Set Port(s) (P20)

 1: 0000   C8..C5 = low/low/low/low

 2: 0101   C4..C1 = low/high/low/high

15: End (P95)

End Program