MID-TERM REPORT: PRECISION ZONE VENTILATION DESIGN **AND CONTROL IN PIG HOUSING**

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Author: Chao Zong
Department of Engineering – Biological and Chemical Engineering, Aarhus University

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Research on this issue regarding experiments and mathematical modelling is essential. Besides, an optimization of precision zone ventilation related to location and design of the ventilation units, the characteristics of direct air supply to the AOZ and analysis of potential approaches will also need to be investigated. The objectives of this project is to develop the knowledge of precision zone ventilation in pig production buildings, aiming at achieving more effective ventilation and improving indoor air quality as well as reducing the required capacity of air cleaning devises.

Keywords: Ventilation and indoor climate; Emission; Computer fluid dynamics; Housing systems

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Chao Zong
Aarhus University, Department of Engineering

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Precision Zone Ventilation design and control in pig housing

Chao Zong

March 5, 2013

1. Introduction to the field of research

The ventilation system of animal houses is important in livestock production due to its significant influence on local thermal conditions and indoor air quality. A well designed, functional, and efficient ventilation system can drive fresh air into a building and remove airborne contaminants effectively. In Denmark, negative pressure ventilation systems with roof exhaust units combined either diffuse ceiling inlet or flap inlet (wall or ceiling flap) are conventionally used in pig housing. Since last decade, ventilation system with diffuse ceiling inlet have become popular for its low investment costs as well as lower supply air velocity which can prevent cold air draft in the animal occupied zone (AOZ) compared with system with flap inlet. However, it also needs more energy to create a larger pressure difference between inside and outside of the building, primarily during summer. Crucially, the air speed is not high enough when it reaches the animal occupied zone which causes a poor efficient convection heat removal for the animals in hot weather. Therefore, in some practices, ceiling mounted either wall or ceiling flap inlets are applied. These ventilation systems are designed to provide perfect mixing of the supply air with the room air to ensure uniform conditions in the entire room (Barber & Ogilvie, 1982; Zhang et al., 1996). Meanwhile, the dispersion and deposition of ammonia and other contaminants are mostly affected by airflow inside the livestock building (Morsing et al., 2008; Zhang & Strom, 1999). The animal house with a high concentration of gases and odours in room air cannot be controlled effectively by a conventional ventilation system with roof or ceiling exhaust units, especially during winter as the minimum ventilation rates employed (Pohl & Hellickson, 1978). Applying a partial pit ventilation system in livestock housing has been studied and used in many cases (Buiter & Hoff, 1998; Wu et al., 2012). Systems with pit exhaust units resulted in acceptable air distribution around the slatted floor and indoor air quality improvement (Saha et al., 2010; Ye et al., 2009).

Precision zone ventilation, consisting of direct air supply into the AOZ and precision exhaust ventilation from the source zone, may provide more efficient climate control and improved air quality. According to the literature, the scientific knowledge is still lacking for correct modelling, design and control of a system with precision zone air supply as well as exhaust in pig housing. Therefore, research on the issue regarding experiments and mathematical modelling is essential. Besides, an optimization of precision zone ventilation related to location and design of the ventilation units, the characteristics of direct air supply to the AOZ and analysis of potential approaches will also need to be investigated.

2. Hypothesis/Aim of the project

Removing the heat and pollutants directly at the sources will reduce the need for ventilation capacity, and result in reduced energy consumption and emission of ammonia and odours. Direct air supply into the animal occupied zone (AOZ) will provide effective thermal control and better welfare for animals during warm weather, especially for a system with only diffuse ceiling inlets. Precision partial source zone ventilation directed at the manure pit, with only a part of the total ventilation capacity, will yield a high effectiveness of the air purification process. Cleaning only the partial exhaust air from the ventilated room space, the requirement on the airflow capacity of the cleaning unit will be reduced. Furthermore, it will reduce the spreading of airborne pathogens between pens.

As a result, the objectives of this project is to develop the knowledge of precision zone ventilation in pig production buildings, aiming at achieving more effective ventilation and improving indoor air quality as well as reducing the required capacity of air cleaning devises.

The project will (1) develop methods to characterize and model the airflow dynamics to utilize differential air mixing (2) generate reveal knowledge on using direct air supply in AOZ and on the influence on thermal condition in AOZ; (3) generate knowledge on applying precision zone exhaust in the AOZ (4) and in manure pit, and (5) provide optimal control criteria and algorithms for the precision zone ventilation.

3. Description of methods

Experimental investigations are carried out both in a pig production facility and in the laboratory. A four-room pig house located at Research Centre Foulum, Aarhus University, Denmark, is used for field investigation. The experimental rooms were designed and built according to a commercial Danish pig production unit. This building was equipped with a negative pressure ventilation system, which is commonly used in pig houses in Denmark. Experiments are also investigated in a two-dimensional ventilation airflow chamber built in the Air Physics Laboratory (APL), Aarhus University, which has the same scale with pig room in length and height, and half scale in width. Ventilation system can be designed accordingly in this 2-D chamber.

The dynamic behaviour of airflow patterns in the room, especially in AOZ and slurry pit can be visualized using laser sheet technology. The two-dimensional Laser Doppler anemometry (LDA) and three-dimensional Ultra-sonic air velocity sensors are used for measuring velocity speed and charactering flow type in the boundary layer. CO_2 is applied as tracer gas to simulate the CO_2 produced by livestock and distribution characteristics. The artificial pigs developed at APL are used to simulate the heat production of pigs at different locations.

Computational Fluid Dynamics (CFD) can effectively model airflow in both spatial and temporal fields, and it was proved the potential to model livestock buildings and can provide concrete flow information. Therefore, in this project, CFD is used to analyse the correlations of pen partition design, air motion and gas concentrations in AOZ and in the head space of the slurry pit.

The investigations include ventilation systems combined with different exhaust units of pig houses. Firstly, systems with roof top exhaust units, total or partial AOZ exhaust ventilation, and pit ventilation will be studied. Secondly, optimization of the locations of inlets and outlet units will be conducted, as well as the air motion in AOZ influenced by the exhaust openings. Thirdly, the system characteristics will be determined by measuring the heat and gas removed from the ventilation system and the capacity required. Fourthly, CFD methods will be utilized to analyse and optimize the system configurations including pen and floor type and the distribution of exhaust points in the pen.

Furthermore, a computer model will be developed to estimate the efficiency, energy consumption and the potential for improving indoor air quality by using the AOZ or pit air exhausts. The modelling work will contain dynamic simulation of the heat production of animals and emission from a production system for a defined period and the results of the exhaust air cleaning as well as energy consumption during the period.

4. Dissemination

Activities:

- Workshop: A case study of airflow patterns around an arched type agricultural building: Investigating mesh convergence of different turbulence models. **Zong, C.**, 2012. Lecture presented at CFD workshop on Modelling of Airflow around a Building with Arched Type Roof & CFD-Benchmark, Aarhus, Denmark.
- Conference: A case study of airflow patterns around an arched type agricultural building: Investigating mesh convergence of different turbulence models. **Zong, C.**, Wu, W., Zhang, G., Shen, X., 2012. Poster presented at CIGR-AgEng2012 on Agriculture & Engineering for a Healthy Life, Valencia, Spain.

Publications:

- **Zong, C.**, Feng, Y., Zhang, G. 2013. Effects of different air inlets on ammonia emission from full scale pig rooms with partial pit ventilation systems. Manuscript.
- **Zong, C.**, Wu, W., Zhang, G., Shen, X., 2013. A case study of airflow patterns around an arched type agricultural building: Investigating mesh convergence of different turbulence models. Submitted to a peer-review journal.
- Wu, W., **Zong, C.**, Zhang, G. 2013. Comparisons of Two Numerical Approaches to Simulate Slatted Floor of a slurry pit model - Large Eddy Simulations. Accepted by *Computer and Electronics in Agriculture*.
- Shen, X., **Zong, C**., Zhang, G. 2012. Optimization of Sampling Positions for Measuring Ventilation Rates in Naturally Ventilated Buildings Using Tracer Gas. *Sensors*, **12**(9), 11966-11988.
- Wu, W., Zhang, G., **Zong, C.** 2012. Emissions of ammonia and greenhouse gases from two naturally ventilated barns for dairy cows. *9th International Livestock Environment Symposium (ILES IX), Valencia, Spain, 8-12 July 2012*, ILES12-0934.

5. Courses

Course title	**Institution**	**ECTS**	**Status**
Introduction course for PhD student	Aarhus University	2	Completed
Biosystems Instrumentation	NOVA Course, Aarhus University	10	Completed
Fundamentals of Ventilation, Indoor Air Quality, Air Motion and Emissions	NOVA Course, Aarhus University	10	Completed
Scientific Writing and Presenting	Aarhus University	2	Completed
Scientific Practice	Aarhus University	1	Completed
Academic English for non-Danish Speaking PhD Students	Aarhus University	3	Planned
The World of Research	Aarhus University	2	Planned

Completed Courses: 25 ECTS; Planned: 5 ECTS; In total: 30 ECTS.

6. Plan for remaining study period

Experimental plans:

a) Experimental studies in the pig barn.

   Working title:

   1. *Production of carbon dioxide from a fattening pig house with partial pit ventilation system*.
   2. *Investigation of temperature and airflow distribution inside a fattening pig room with partial pit ventilation system*.

b) Experimental studies of velocity and temperature distribution in a full scale 2-D chamber of pig house.

   Working title:

   1. *Design and optimization of a 2-dimensional flow chamber for precision zone ventilation study*.
   2. *Experimental study of ventilation effectiveness and air velocity distribution in a model pig house;*
   3. *Experimental and numerical investigation on velocity and temperature distribution in a model pig house with direct air supply;*
   4. *Optimization of locations of inlet and exhaust units and the influence on airflow pattern in a full scaled 2-D chamber of pig house;*

It is planned that each working title will produce one publication.

Study abroad:

We plan to visit Ji-Qin Ni, Department of Agricultural and Biological Engineering, Purdue University at West Lafayette for about three months (August-November, 2013).

Reference:

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Zhang, G., Strom, J.S. 1999. Jet drop models for control of non-isothermal free jets in a side-wall multi-inlet ventilation system. *Transactions of the Asae*, **42**(4), 1121-1126.

7. Appendix

Effects of different air inlets on ammonia emission from full scale pig rooms with partial pit ventilation system

Chao Zong[1], Ying Feng[1,2], Guoqiang Zhang[1*]

[1]Department of Engineering, Aarhus University, Blichers Allé 20, P. O. Box 50, 8830 Tjele, Denmark

[2] Beijing Agricultural Machinery Institute, 100083 Beijing, China

Abstract

Ammonia emission from pig house is a big issue to neighbouring atmospheric environment. Demands to reduce ammonia emission from livestock production, especially swine industry, are growing in Denmark. It is assumed that applying an additional pit exhaust unit can remove the highly polluted air from the slurry pit directly. The exhaust air can be treated with an air purification system, which will lower ammonia emission. Furthermore, a partial pit exhaust unit in a ventilation system with different types of inlets will affect the total ammonia emission from pig house and the efficiency of the partial pit ventilation to reduce emissions. In this study, two experimental rooms with different ventilation air inlet were applied to investigate the performances of the partial pit ventilation effects by air supply. Each room had 32 pigs evenly distributed in 2 pens. Both rooms were using negative pressure ventilation systems with both ceiling and pit exhaust units, one combined ceiling inlet (diffusion air inlet and flap jet inlet), where diffusion inlet operated the most time and ceiling flap inlet operated under warm summer hours(C+P); another one with wall jet air inlet (W+P). The maximum ventilation

[*] Corresponding Author. Tel. +45 8715 7735, Fax. +45 8715 6076
Email Address: Guoqiang.Zhang@agrsci.dk (Guoqiang Zhang)

capacities for both rooms were set as 3000 m^3/h. Both pit exhausts were operated with 10% of the maximum ventilation capacity for the whole experiment period. The ceiling ventilator as major exhaust unit was automatically controlled by computer according to indoor thermal conditions. Flow rates in all ventilation units were measured and recorded continuously, same with ammonia concentrations, which were measured at air inlet, ceiling exhaust and pit exhaust for both rooms. The temperatures inside these two rooms were maintained around 20 ^oC. Results showed that ventilation rate in the room with W+P ventilation system was higher than that in the room with C+P. However, ammonia concentration from ceiling and pit exhaust air with W+P was 30% higher than those with C+P. The total ammonia emission from room with C+P was 22% lower than room with W+P. We conclude that partial pit ventilation system with diffusion ceiling air inlet produce less ammonia emission and can better improve the indoor air quality than the one with wall jet air inlet.

1. Introduction

Ammonia is a key parameter for evaluating the air quality as it has a significant impact on the health of both human beings and animals. Livestock production is recognized as a major source of ammonia emission, which can cause a lot of problems to the neighboring atmospheric environment (Hutchings et al., 2001; Sommer et al., 2006). The demands for reducing ammonia emission are increasing in most European countries. S. Gyldenskærne et al. (2007) estimated that 97% of the emission was related to animal husbandry activities. Ammonia emission in Denmark got reduced from 109,900 tonnes NH_3-N per year to 80,400 tonnes NH_3-N per year from 1990 to 2004. The 1999 Gothenburg Protocol required Denmark to abate the emission to 56,800 tonnes NH3-N/year by 2010. A further reduction of 53,200 tonnes/year is expected in the new *projection of ammonia emission in Denmark from 2005 until 2025*.

Therefore, numbers of technologies have been developed to achieve the goal of reducing ammonia emission. Different kinds of ventilation systems as well as air purification systems are the most considerable methods been under used (Saha et al., 2010).

Almost all the pig houses in Denmark are equppied with mechanical ventilation system, which can maintain indoor thermal condition comfortable and keep humidity and the gaseous contaminants generated from animals' activity and their waste at desirable levels. The indoor air quality and thermal condition in a pig barn depend on how efficient the ventilation system is. The design of ventilation system, like the types and locations of air inlets and outlets etc., can affect airflow characteristics inside a room. Airflow patterns may affect ammonia and other gaseous contaminants dispersion and deposition (Arogo et al., 2003; Buiter & Hoff, 1998; Ye et al., 2008; Zhang & Strom, 1999). Due to the importance of the effect of ventilation system on micro-environment inside the pig barn, a partial pit ventilation system was introduced into livestock houses, which attracts lots of investigations. Polluted air in the headspace of a pit might be removed directly through the pit exhaust before exchanging to the room space above the slatted floor, which would improve air quality inside room. It is easier to clean concentrated pit exhaust air with air purification system (Saha et al., 2010).

Many researchers have studied pit ventilation system employed in animal houses. Scale model studies are popular in this area as experimental condition is easy to be controlled and model experiment expenses become much less. Pohl and Hellickson (1978) investigated the performance of five types of pit ventilation systems in a 1/12 size scale model swine finishing building and found centred duct pit ventilation system performed the best. Effects of building design and management factors on the distribution of ammonia in a one half scale model were studied by Buiter and Hoff(1998). Those scale model investigations got good results on pit ventilation application. However, full scale study is recommended as scale model may not be representative of actual situation. Saha et al. (2010) studied the effects of a partial pit ventilation system on indoor air quality and ammonia emission from a full scale fattening pig room. The ventilation system in the room consisted of ceiling diffusion air inlet, a ceiling-roof top ventilator as a major exhaust unit and an extra pit exhaust unit. This study concluded that ammonia emission could be significantly reduced by using partial pit ventilation system together with purification system. The capacity required for air cleaning was only 10% of the maximum total exhaust air. The partial pit ventilation system worked well both in model and full scale experiments. However, a partial ventilation system with other air inlet like wall inlet in a full scale pig barn has not been reported in previous studies. Hence it is of interest to compare partial pit ventilation systems combined with different kind of air inlets.

Therefore, the objective of this study is to investigate the effects of partial pit ventilation systems combined with two kinds of air inlets, wall jet inlet and combined ceiling diffusion/jet inlet, on indoor air quality and ammonia emission from a fattening pig house.

2. Materials and Methods

2.1. Pig house

Two of the four-room pig house (Fig. 1) located at Research Centre Foulum, Aarhus University, Denmark, were used for this investigation. The dimension and layout of the experimental room were designed and built according to a commercial Danish pig production unit. Each room had two pens (4.8m long and 2.45m wide) equally divided by a 1 m high partition wall, an inspection alley with a width of 0.9 m close to the door side (Fig. 1a). All pens were equipped with two thirds fully slatted and one third drained floors. The opening ratio of the slatted floor was 18.2% and 8.6% for drained floor.

Each pen had its own slurry pit which was built underneath the slatted floor with a depth of 0.7 m. Slurry can be pumped out to an slurry tank outside through the a valve beneath each pen. One feeder and two drinkers were installed in each pen, which could supply feed and water automatically to pigs. These two rooms were connected by a corridor in the middle with 2.3 m in width. These rooms were constructed with feasibility for varied ventilation systems and operation strategies.

2.2. Ventilation systems

The experimental building was designed and equipped with a negative pressure ventilation system, which is commonly applied in Denmark. Each room had two exhaust units, which were placed in the same pattern for both rooms. All of the exhaust units run continuously through a same period as the fattening pigs growing.

Ceiling exhaust unit was a chimney duct installed as the major outlet in the pig room (Fig. 1b). The exhaust opening was 0.46 m in diameter beneath the ceiling near the door side. Inside the chimney duct, there was a fan (VengSystem A/S, Denmark) of 0.45 m diameter accompanied with a frequency converter (Type Frenic-Mini, VengSystem A/S, Denmark) to measure airflow rate. The ventilation rate was controlled by an analogue actuator (VE245, VengSystem A/S, Denmark). The capacity of the ceiling exhaust was 5000 m^3h^{-1} at 40 Pa static pressure. However, the maximum ventilation rate for each room was pre-adjusted as 3000 m^3h^{-1} for this investigation. During the experiments, the ceiling exhaust which was also the major exhaust unit was automatically controlled by VengSystem software according to indoor thermal conditions.

The other exhaust unit was placed under the slatted and drained floor as the partial pit outlet. Four exhaust openings made of *polyvinyl chloride* (PVC) tubes with 0.16 m in diameter were installed in the side pit wall for each pen. The exhaust air from the manure pit was sucked through the eight pit openings of each room into a mixing chamber located at the side of the building, and further then through a duct to outside. The pit ventilation rate was operated at 10% of the maximum ventilation rate of 3000 m^3/h for both rooms during the experiment.

Both investigated rooms were equipped the same exhaust units. The difference between these two rooms was the type of air inlet units. Room 1 was installed ceiling diffusion air inlet), while room 2 was wall jet air inlet

2.2.1. Room 1 with diffusion ceiling and ceiling jet air inlets plus partial pit ventilation system(C+P)

Three air inlet ducts with 0.8m in diameter located in the building ridge above the ceiling let outside air came into the building attic, figure 1. The attic above room 1 was connected with the space with those three ducts. The room ceiling was made of porous materials, which could diffuse the air from the attic into the room. Two ceiling jet air inlets distributed evenly near the door side were built in the ceiling. Normally, these two ceiling inlet jets were closed. When inside temperature was very high, ceiling jet inlets would open to increase the air speed in pig occupied zones. This process was controlled by VengSystem using a set temperature point of 20.4 ℃with 5℃ P-band. Fresh air from outside entered the attic through the ducts in the ridge, passed the porous ceiling and diffused into the room space. , 2.2.2. Room 2 with wall jet air inlets plus partial pit ventilation system (W+P)

Room 2 was equipped two wall air inlets on the sidewall close to windows (Fig. 1b). The two wall inlets were the same size of 0.62×0.24m. Both wall jets were placed 1.83m high from the floor, and evenly distributed along the side wall. The inlet openings were regulated automatically together with exhaust fan speed.

2.3. Animals and feeding

The pigs were raised over 78 days in this experiment, from 6th August to 23th October, 2012. A total number of 64 pigs was randomly picked and equally divided into the four pens of the two rooms. Measurement of weight was taken 3 times in the whole growing period. The initial average weight of the pigs was about 30 kg/pig and mean final weight was 111.8 kg/pig. Each pen was equipped two feeding and drinking facilities. The drinking troughs were located close to side wall, while the feeders were attached on the partition wall in each room (Fig.1a). Feed and water were supplied automatically. Pigs were first fed with the complete fodder for pig "dlg Sv Ener Prof Helse U 1kv2012" (dlg a.m.b.a., Copenhagen, Denmark), which contained 41.9% wheat, 30% barly, 17.5% soybean, 4.9% wheat bran, 2% cane molasses, 1.33% calcium carbonate (chalk), 0.7% coconut fat, 0.45% feed salt and vitamins and minerals, until they grew up to approximate 55 kg (5th September, 2012). After that, those pigs got another complete feed mix called "dlg Svin Enh Bas Helse U 1kv2012" (dlg a.m.b.a., Copenhagen, Denmark) consisting of 40% wheat, 25% barly, 10% rapeseed, 6.4% soybean, 5% wheat bran, 4.1% sunflower seed, 3.3% triticale, 2.5% cane molasses, 1.2% calcium carbonate (chalk), 0.8% coconut fat, and some vitamins and minerals. Straw was put in the drained floor area as a rooting material based on Danish regulations.

2.4. Measurements

2.4.1. Ventilation airflow rates and air velocity inside the room

Ventilation rates through the ceiling and pit exhaust units were measured and recorded automatically by the VengSystem (VengSystem A/S, Roslev, Denmark). The flow rates in all exhausts were measured based on the pulse signal generated when the propeller rotating, which was linear with the air flow rate. The measurement devices (REVENTA® GmbH & Co. KG, Germany) were pre-calibrated.

2.4.2. Ammonia concentration

Ammonia concentrations in sample air collected from (i) the attic just beneath the roof inlet ducts (Room 1 background), (ii) the ceiling exhaust unit in room 1, (iii) the slurry pit exhaust pipe of room 1, (iv) the outside of the wall inlet of room 2, (v) the ceiling exhaust unit in room 2, (vi) the slurry pit exhaust pipe of room 2, were measured by an infrared 1412 Photoacoustic Field Multi-Gas Monitor and a 1309 Multipoint Sampler (INNOVA Air Tech Instruments A/S, Denmark).Six pumps (Model-CAPEX L2,Charles Austen Pumps Ltd., UK) connected with FEP (Fluorinated ethylene propylene or Teflon-FEP) tubes were used to suck the air samples from the above mentioned locations to the multi-gas analyser.

2.4.3. Air temperature and relative humidity

Temperature and relative humidity inside both rooms and outside the pig house were measured by VE10 Temperature Sensors (VengSystem A/S, Denmark) and recorded using VengSystem software database. Besides, type T thermocouples were also used to measure the air temperature (i) in the attic (air inlet of room 1), (ii) outside the wall jet inlets of room 2, (iii) inside both rooms, one 2 m above the fully slatted floor and the other 2 m above the drained floor of each pen. Relative humidity was regularly checked using VELOCI CALC. (TSI Inc., USA).

2.4.4. Slurry depth

Slurry depth was measured twice a week at the same position in each pen. Slurry tank would be empty as the slurry depth was more than 30 cm.

2.5. Observations

The behaviors of the pigs in each pen were monitored by total of four video cameras (Storage Options, China), two in each room. Videos were recorded by the Video Server (Storage Options, China) and transferred to the computer via an internet cable. Recording the video of the pig's behavior in each room was set automatically with 1 h intervals. The recorded videos were used to identify the number of lying pigs and standing pigs in each pen, and where those pigs were located.

2.6. Computation of ammonia emission rate and data analysis

The following equation was used to calculate the ammonia emission:

$$E_{NH_3} = V(C_{out} - C_{in})$$

where E_{NH_3} is the ammonia emission either from the ceiling exhaust unit or from the pit exhaust unit, mg h^{-1} pig^{-1} or mg d^{-1} pig^{-1}; V is the ventilation rate, either for ceiling or pit, m^3 h^{-1} pig^{-1} or m^3 d^{-1} pig^{-1}; C_{out} is the outlet ammonia concentration of either room air or pit exhaust air, mg m^{-3}; C_{in} is the inlet ammonia concentration from attic for room 1 and from side wall inlet for room 2, mg m^{-3}.

3. Results and discussion

There are some data not included in this article during the period from 10th to 14th in September due to some setting of the ventilation system changed at that time, which didn't affect the measurements afterwards.

3.1. Climate and ventilation rate

The mean value of climate during the experiment is shown in Table 1. Mean temperature and humidity in the two rooms (room 1 with wall inlet, room 2 with ceiling diffuse inlet) were similar to each other. Compared with outside temperature which was lower and changed frequently during day and night, the temperatures inside these two rooms were maintained as 20 ℃ with a standard deviation of ±1.5 ℃. The relative humility (RH) inside these two rooms were also similar with each other like inside temperatures, while RH in room 1 was a little higher than RH in room 2. Outside humidity was around 33% higher than those inside. Higher thermal condition inside could create more evaporated water vapour which would be taken away by the mechanic ventilation systems. Besides, higher flow air rate would also cause more water evaporation, and the measuring position located in the ceiling of the room where the wind speed was high.

The average ventilation rate through ceiling exhaust in room 1 was higher than the one in room 2, and with a lower variance during the measuring period. There was no such big difference for pit ventilation rates which were 9.85 (±0.71) and 9.31 (±0.61) $m^3h^{-1}pig^{-1}$ in room 1 and room 2, respectively. The mean day and night (24 h) pattern (Fig. 2) shows the same feature. The average ceiling ventilation rates in both rooms followed a similar pattern to the outside temperature: low in the night and high in the day time, while the pit ventilation rates were maintained at 9.0-10.3 $m^3h^{-1}pig^{-1}$.

The patterns of mean temperature and ceiling ventilation rates during the pigs' growing period are shown in Fig. 3. Same with the mean day and night (24 hours) pattern showed in Fig. 2, the patterns of ceiling ventilation rates in both rooms were similar with outside temperature. The ceiling ventilation rate in room 2 with wall jet inlet was lower and changed more rapidly and dramatically than room 1 with ceiling diffusion inlet. This was because when the outdoor air came into room 1, it needed to go through the attic first and then pass through the diffusion ceiling. Due to the high resistance of the diffusion ceiling, the inlet air speed was lower, and the temperature of the supply air was also warmed little up by the ceiling materials. However, for room 2, as the outside air came into the room directly through the windows and the inlet area was much smaller, the inlet air was cooler and speed was higher.

Since this experiment was conducted during the period from 6th, August to 23th, October in 2012, the daily mean outdoor temperature decreased a lot (Fig. 2). However, the ceiling ventilation rates in both rooms just decreased slightly. This was caused by the increment of pigs' heat production with body weight growing.

3.2. Ammonia concentration

The average ammonia concentrations measured at different locations in the two rooms with different ventilation systems are shown in Table 2. The ammonia concentrations both at ceiling exhaust and pit exhaust in room 2 were much higher than those in room 1. The mean ammonia concentration in the ceiling exhaust air with ventilation system as W+P was 3.44 ppm and 63.8% higher than the one with ventilation system C+P. For pit exhaust air, it was 28% higher in room 2 than room 1. Besides, higher fluctuations were also found in room 2 with W+P ventilation systems. It is reasonable since air motion was stronger due to wall inlet jets in room 2. High speed airflow in the pig room would cause more turbulent vortex in the animal occupied zone and near the slatted floor area which could make more gaseous ammonia released from the surface of manure and floor.

Fig. 4 shows the daily mean ammonia concentrations at different locations during the growing period of finishing pigs. The concentrations in the room and pit air increased overall with some fluctuations as the pig was growing. Like the overall mean value we found in Table 2, the daily average concentrations were also higher in room 2 than room 1 during the whole measuring period. In the first three days (6th to 8th of August) when the weaning pigs were put into these two rooms, the ammonia concentrations in exhaust air from room and pit in both rooms increased rapidly. After that, concentrations in all the measured locations steadily increased until the mid of the growing period. Since 14th of September, the concentrations in the pit exhausts of both rooms increased rapidly again with large fluctuations until the end of the growing period. This might be caused by the change of feed after 5th of September. The pigs gained more weight daily after that date than before (6th, August – 5th, September: 0.8 kg pig^{-1} d^{-1}; 5th September to the end: 1.2 kg pig^{-1} d^{-1}), which indicated those pigs would produce more waste, and thus ammonia concentration became higher.

The patterns of mean ammonia concentrations at the same hour of a day and night (24h) during the measuring period are shown in Fig. 5. It is clear that the concentration at each location was stable during a day and night period (24h). It is known that the ammonia released from pig house is related to the temperature of the manure and room air. Although the outside temperature changed dramatically from day time to the night, inside temperatures in both rooms were keep fixed.

3.3. Ammonia emission

From Table 2, we can find that there was approximately 52% ammonia emission from the ceiling in room 1, and the amount for room 2 was 53%. The total ammonia emission from room 1 was about 22% less compared with room 2. Higher variances were observed in room 2 than room 1.

Emission from all exhausts increased following pig's growth?? (Fig. 6). As a matter of fact, since the pit ventilation rates in both rooms were controlled at almost the same level during the whole growing period, the emissions from the pit exhausts followed the similar pattern as concentrations. More airflow rate through ceiling in room 1 than room 2, while higher ammonia concentration was accumulated in room 2 than room 1. As a result, ammonia emission through ceiling exhaust in room 2 was found higher than in room 1, which followed the similar pattern with emission from the pit. Compared with emission through pit exhausts, emissions from the room had more variation.

Fig. 7 shows the mean ammonia emissions from different locations at the same hour of a day and night (24h) during the investigation. The patterns of ammonia emission through ceiling in a day and night were similar to each other for both rooms, which also followed the patterns of ventilation rates and outdoor temperature (Fig.1). Low emission was found in the evening and there was a broad peak of emission in the afternoon. In order to maintain the indoor climate comfortable for the animals, ventilation rate, especially for the one through ceiling, would be adjusted accordingly. As a result, larger amount of airflow rate would result in higher emission. This was also pointed out by other studies with different ventilation systems (Saha et al., 2010). Pit ventilation rates for both room were keep constant all the time, and an almost fixed emission through the pit in a day and night.

3.4. Animal activities

The microclimate in the pig room need to be controlled comfortable for the pigs living inside, and also activities of animals can affect the indoor climate. The activities like eating, drinking or lying for the pigs would affect the air distribution not only in the animal occupied zone but also in the headspace of the slurry pit. When the pig lies on the floor, it will occupy more space than the one standing there. The movements of animals will create a lot of small turbulent vortex.

There was no significant difference on activities between the pigs lived in these two rooms. The average weights of pigs in both rooms were close with each other at the end of the growing period.

4. Conclusion

Two types of partial pit ventilation system were investigated and compared in this study. A partial pit ventilation system with diffusion ceiling inlet needed more ventilation capacity to maintain indoor thermal environment than the system with wall jet inlet in hot period in Denmark. However, the ventilation system with wall jet inlet could create more turbulences and increased ammonia concentration. The total ammonia emission was higher from the room with wall inlets than the one with ceiling inlet.

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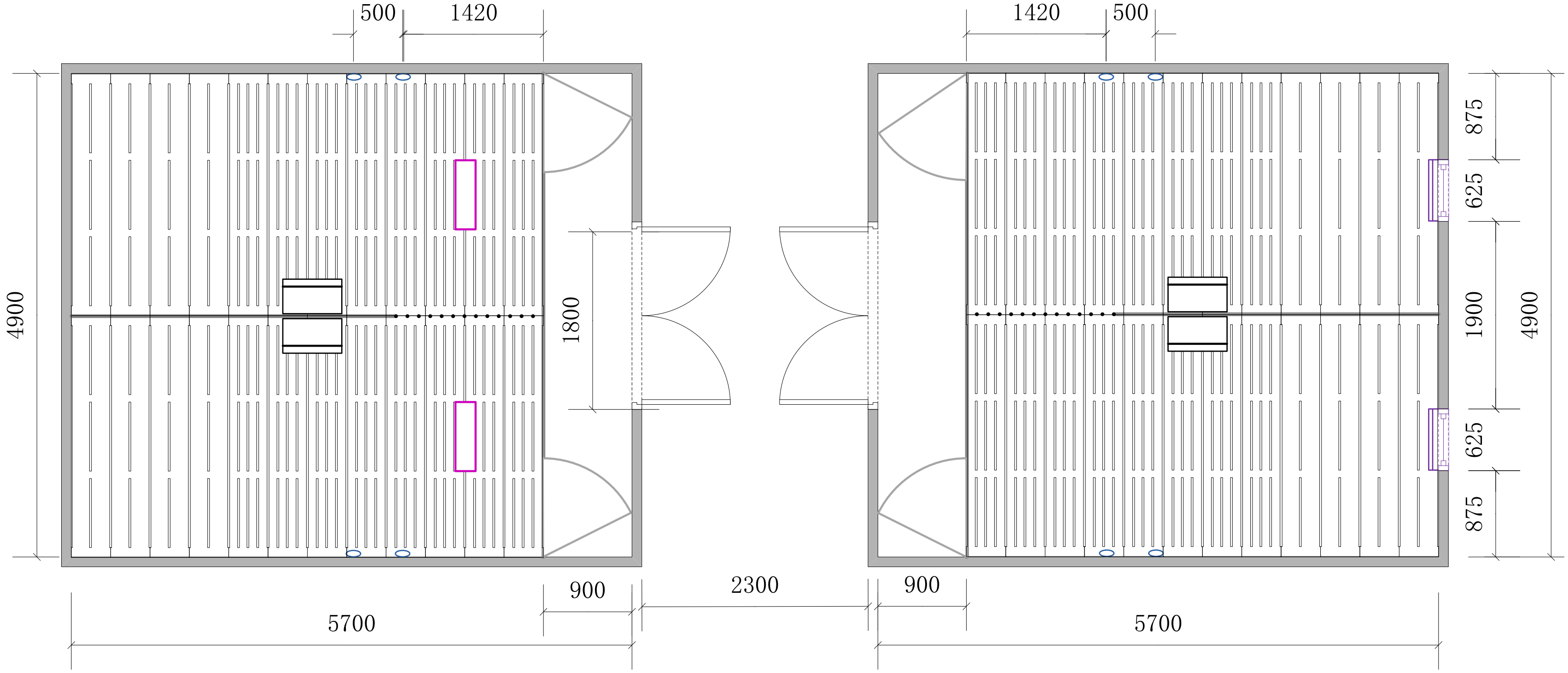
Tables and Figures

Table 1 – Means and standard deviations (in brackets) of temperatures at the different locations and the ventilation rates through the ceiling and pit

Measurement locations	Room 1 (with ceiling inlet)	Room 2 (with wall inlet)	Outside
Temperature (^oC)	20.34 (1.54)	20.76 (1.54)	14.26 (4.12)
Humidity (%)	58.00 (6.64)	56.94 (5.59)	76.00 (11.86)
Ceiling ventilation rate ($m^3h^{-1}pig^{-1}$)	83.36 (16.32)	68.14 (19.49)	--
Pit ventilation rate ($m^3h^{-1}pig^{-1}$)	9.85 (0.71)	9.31 (0.61)	--

Table 2 – Means and standard deviations (in brackets) of daily values of ammonia concentrations at different locations and the ammonia emissions through ceiling and pit exhausts

	Measurement locations	Room 1 (with ceiling inlet)	Room 2 (with wall inlet)	Effect of ventilation systems
Ammonia concentration, ppm	Ceiling exhaust	2.10 (0.69)	3.44 (1.36)	
	Pit exhaust	16.62 (6.73)	21.27 (9.06)	
	Outside	0.58 (0.15)	0.45 (0.13)	
Ammonia emission, mg $h^{-1}pig^{-1}$	Ceiling exhaust	120.7 (40.81)	158.88 (62.33)	
	Pit exhaust	111.45 (48.13)	140.2 (61.5)	
	Total	232.15	299.08	


500
1420
1420
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1800
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625
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4900
625
875
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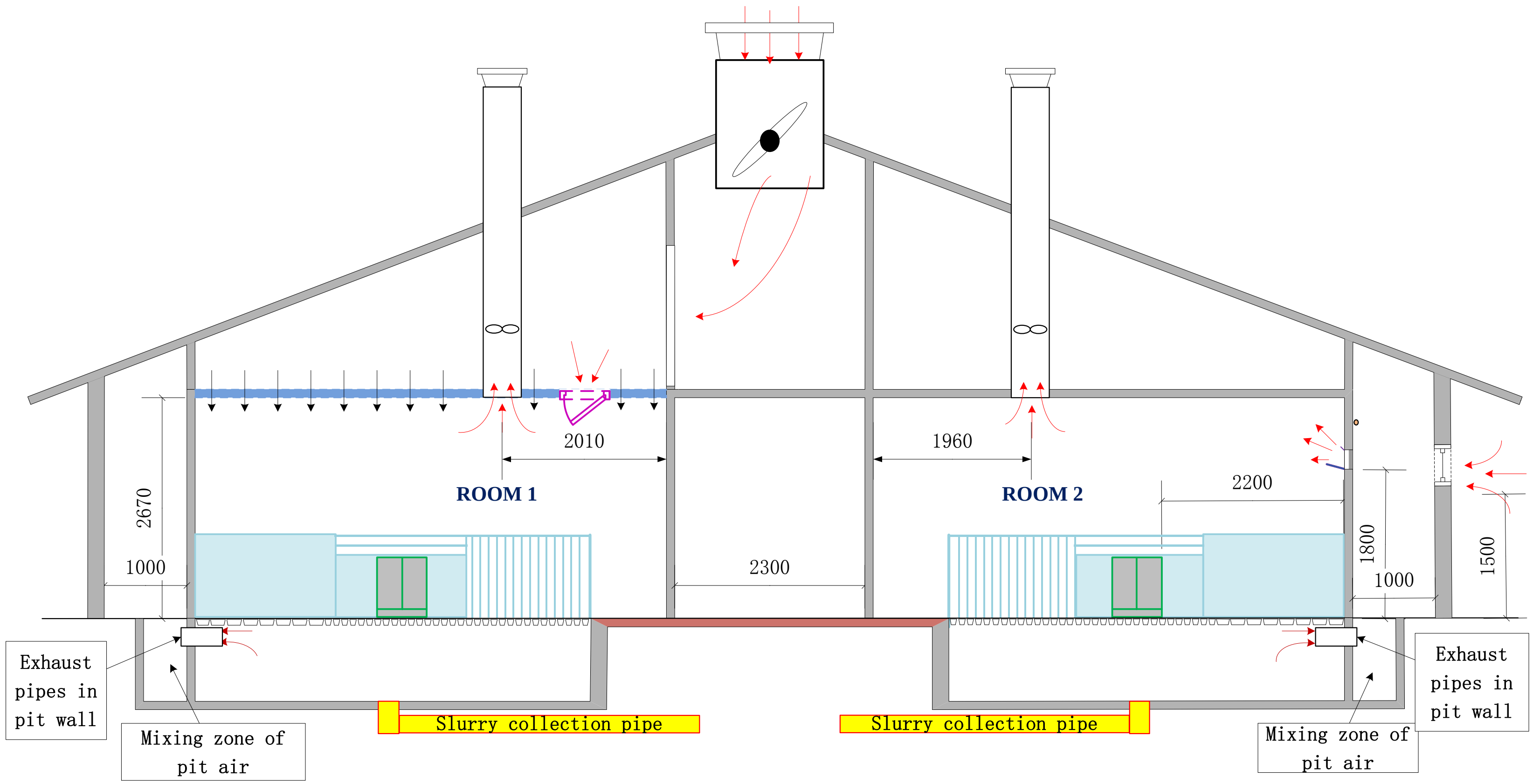
2300
900
5700
5700

(a)



(b)

Fig. 1 – Layout of the experimental building: (a) the plan, (b) the front elevation. All dimensions are in mm.

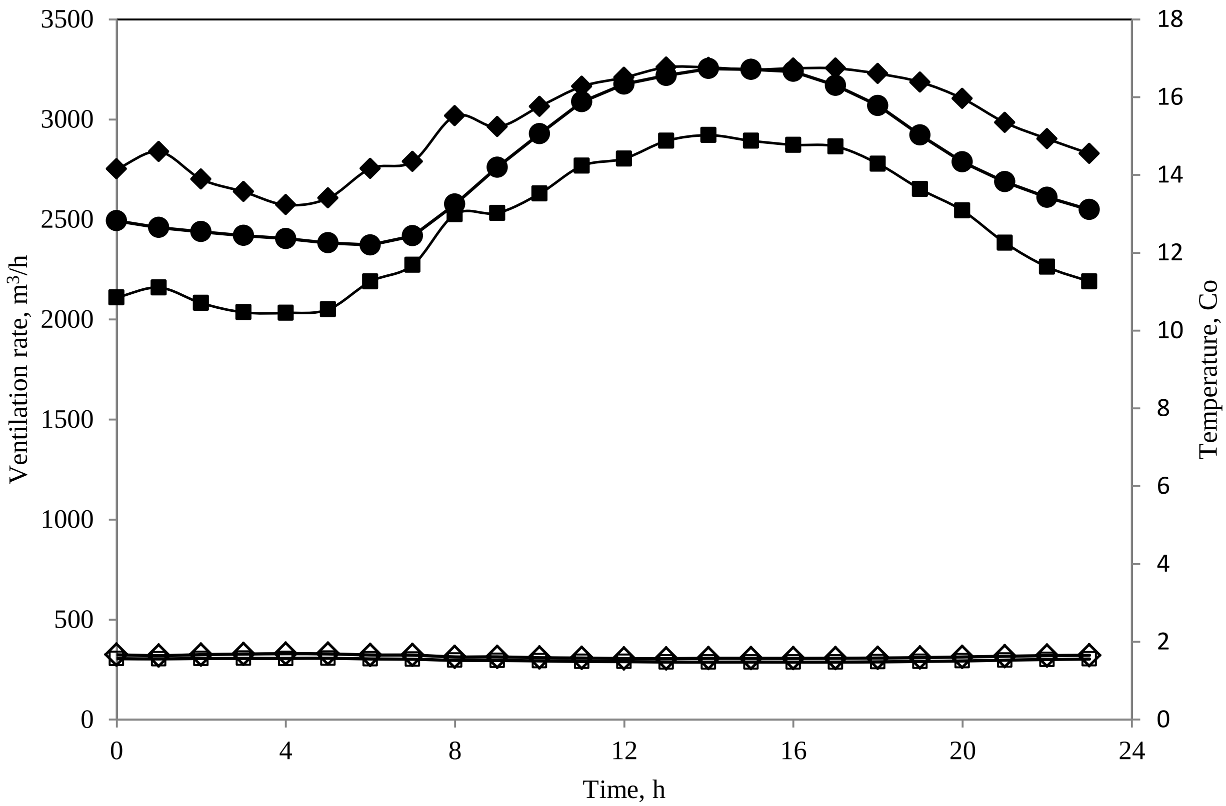


Fig. 2 – Mean ventilation rates and temperature at the same hours of a day and night (24 h) during the measuring period: solid diamond – total ventilation rate of room 1; solid square – total ventilation rate of room 2; diamond – pit ventilation rate of room 1; square – pit ventilation rate of room 2; solid circle – outside temperature.

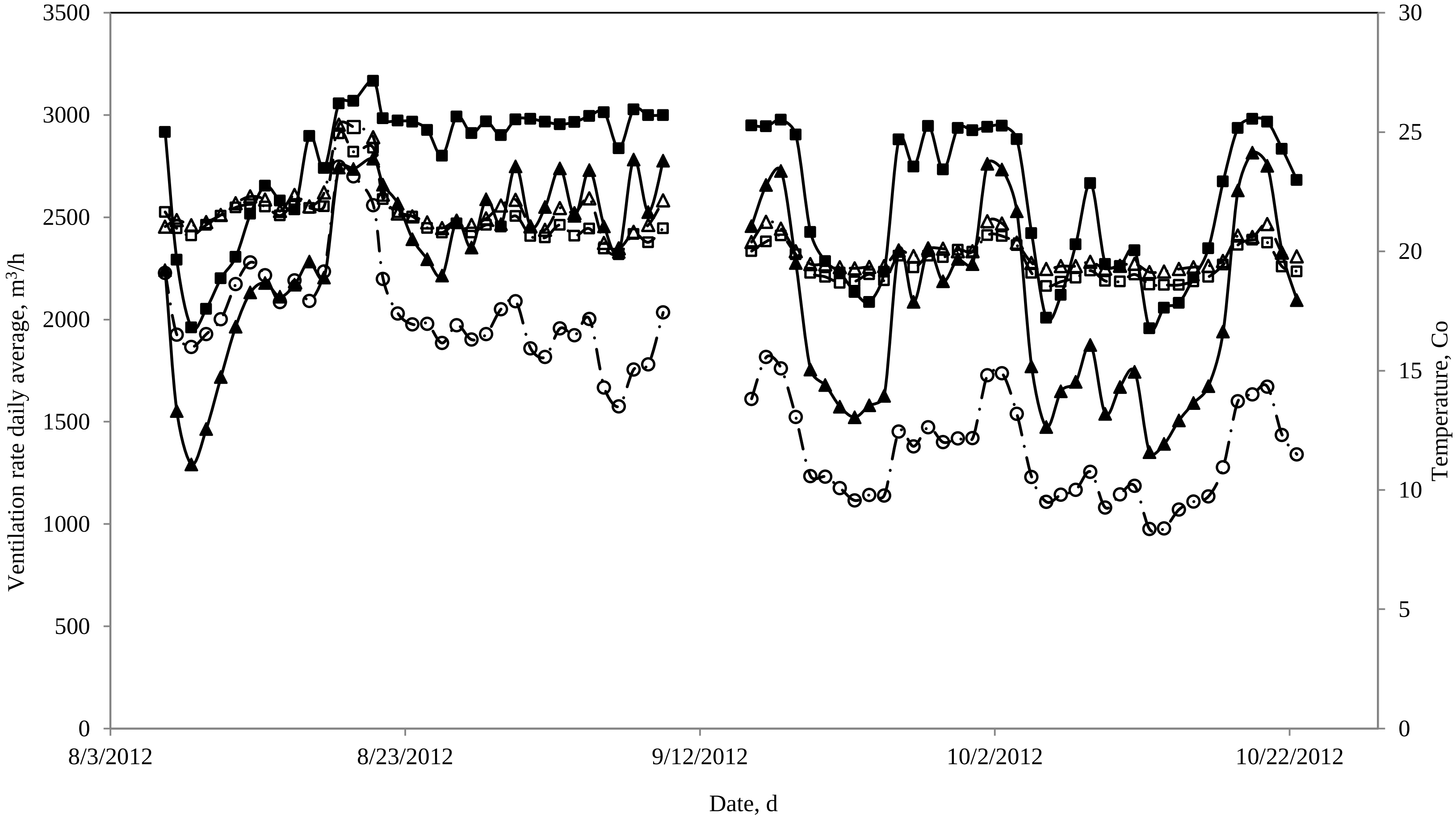


Fig. 3 – Daily mean outside and room temperatures and ceiling ventilation rates during the pigs' growing period: solid square with solid line – ceiling ventilation rate of room 1; solid triangle with solid line – ceiling ventilation rate of room 2; square with long dash dot line – room 1 temperature; triangle with long dash dot line – room 2 temperature; circle with long dash dot line – outside temperature.

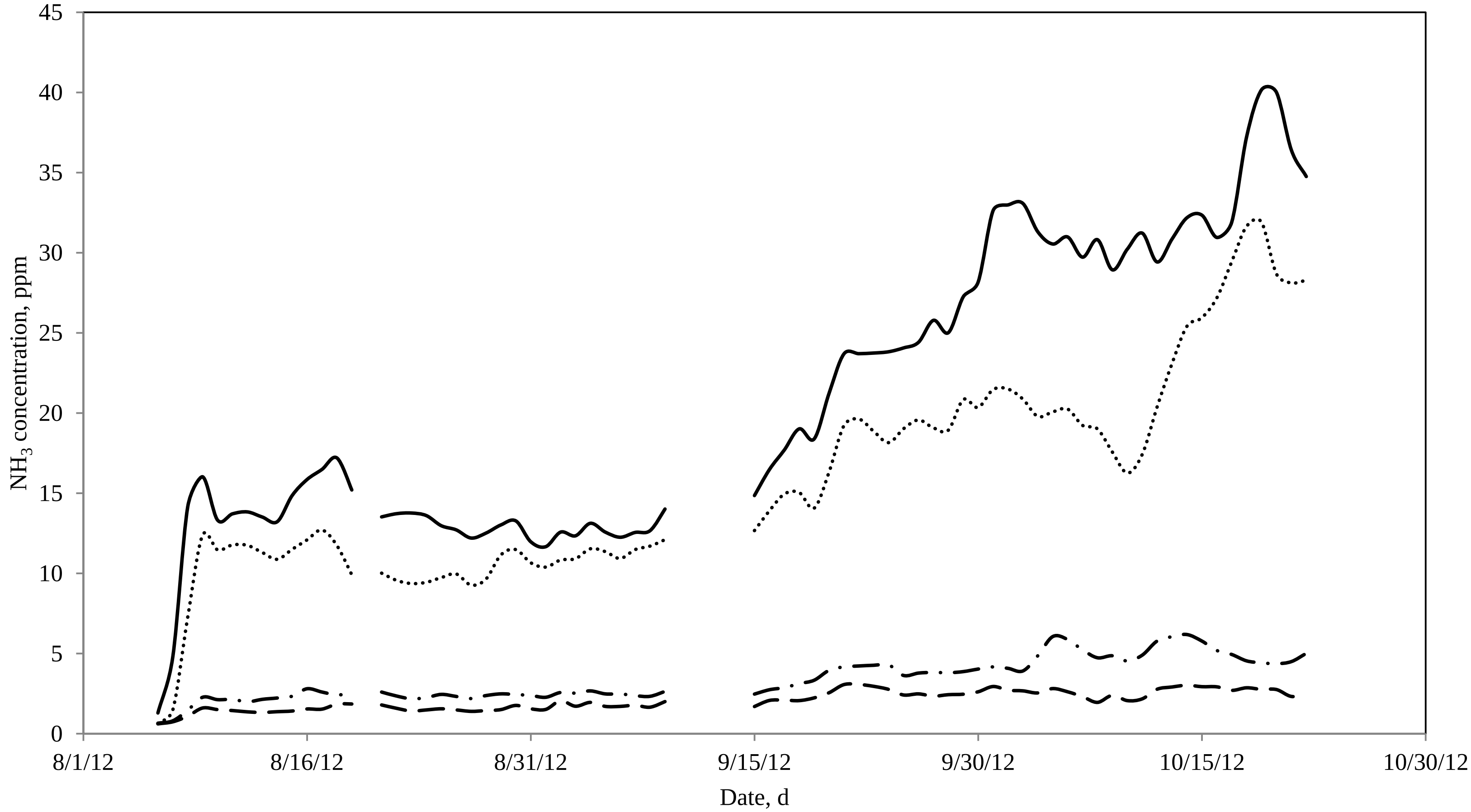


Fig. 4 – Daily mean ammonia concentrations at different locations during the experiment: solid line – room 2 pit exhaust; dot line – room 1 pit exhaust; long dash dot line – room 2 ceiling exhaust; dash line – room 1 ceiling exhaust.

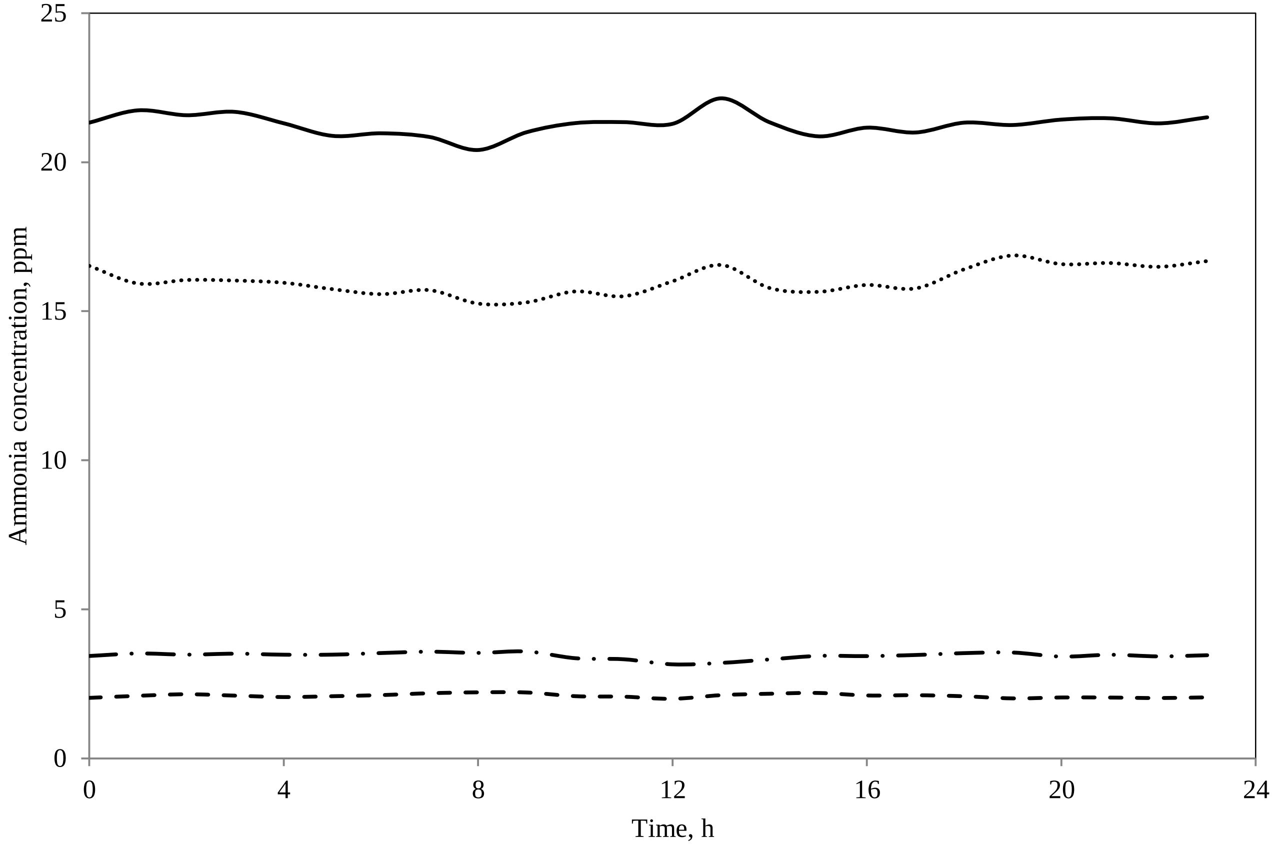


Fig. 5 – Mean ammonia concentrations at the same hours of a day and night (24h) during the measuring period measured at different locations: solid line – room 2 pit exhaust; dot line – room 1 pit exhaust; long dash dot line – room 2 ceiling exhaust; dash line – room 1 ceiling exhaust.

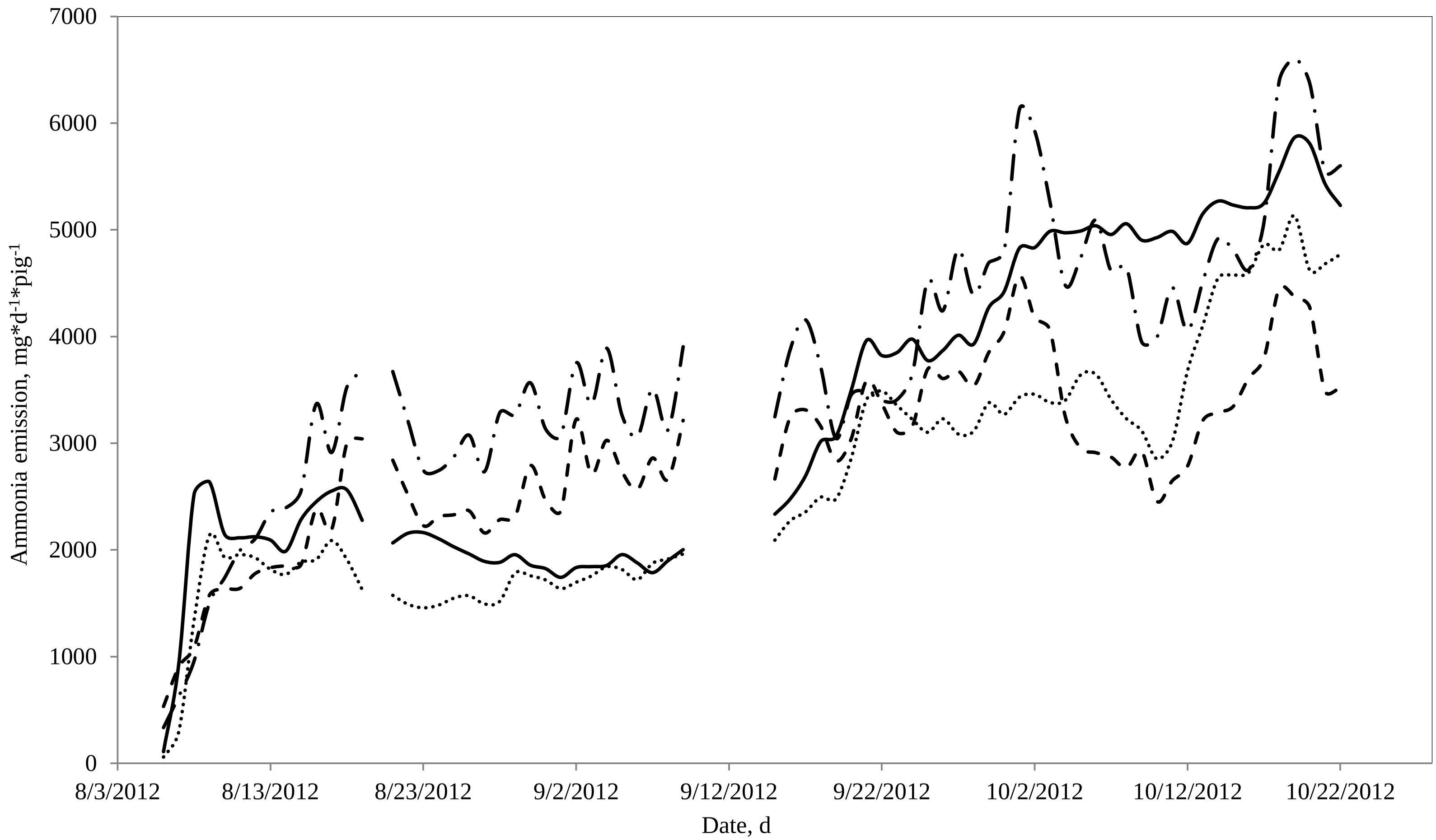


Fig. 6 – Daily mean ammonia emissions from different exhausts of each room during the experiment days: solid line – room 2 pit exhaust; dot line – room 1 pit exhaust; long dash dot line – room 2 ceiling exhaust; dash line – room 1 ceiling exhaust.

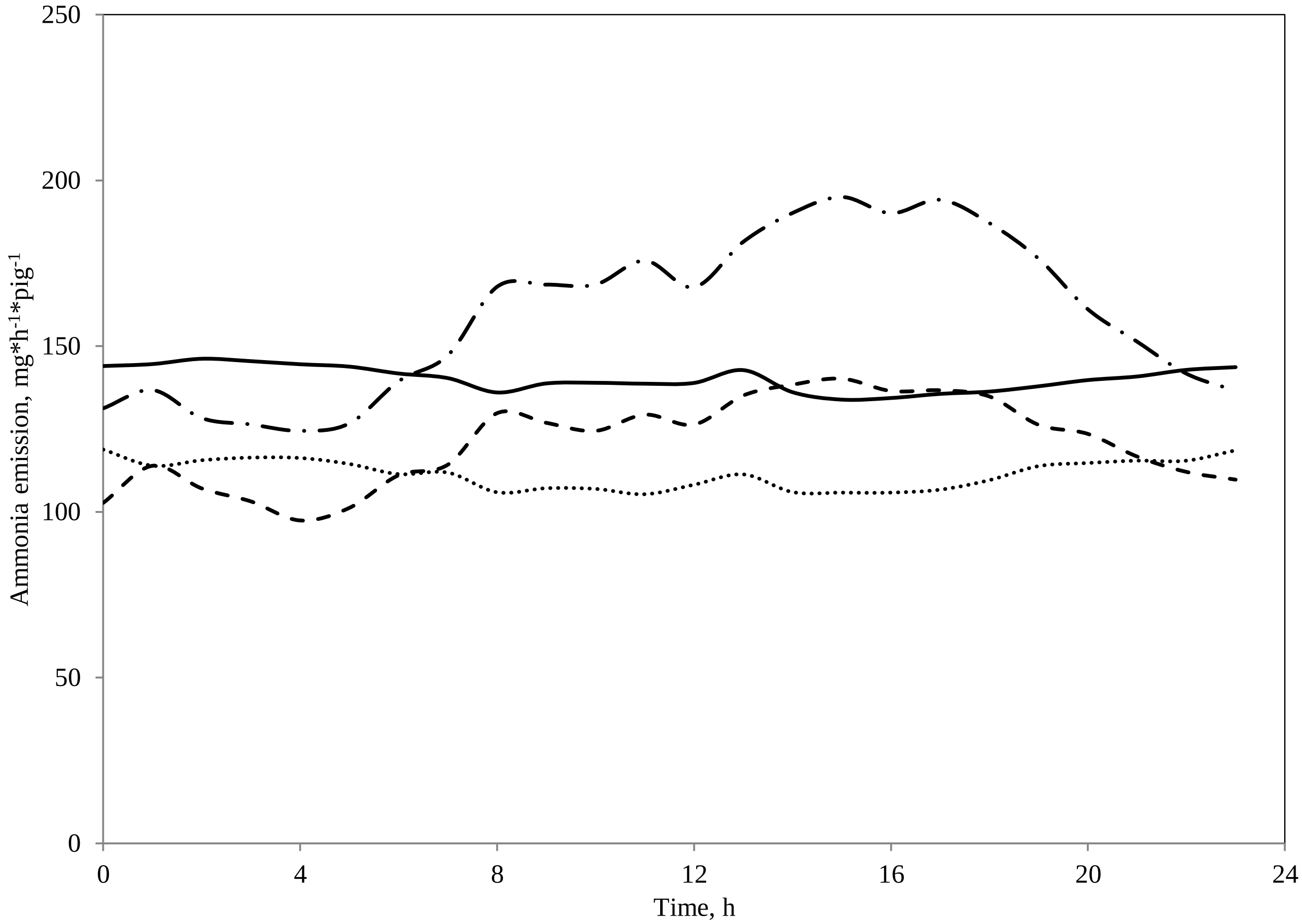


Fig. 7 – Mean ammonia emissions from different locations at the same hours of a day and night (24 h) during the pig's growing period: solid line – room 2 pit exhaust; dot line – room 1 pit exhaust; long dash dot line – room 2 ceiling exhaust; dash line – room 1 ceiling exhaust.

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Department of Engineering
Aarhus University
Edison, Finlandsgade 22
8200 Aarhus N
Denmark

Tel.: +45 4189 3000