# Aerial pollutants on a pig farm in peri-urban Beijing, China

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**Abstract:** The study was carried out to evaluate the airborne gases and suspended particulate matter concentrations in the pig barns of a commercial pig farm situated in the peri-urban area of Beijing, China. The measurements followed the natural pig life-stages namely: gestation, farrowing, weaning, and fattening. In order to accomplish these objectives, three different measurement devices were employed: (i) color diffusion tubes, (ii) a portable gas measuring device, and (iii) a dust measuring instrument. Due to the rotation of the devices in the different sampling places, the measurements were performed at different time periods during the months of the summer and winter season in Beijing. The pig farm had a capacity of 15 000 pigs per year and the manurial system was identified as “gan qing fen” or dry cleaning of the manure. The main by-products generated by the farm were irrigation water and small-scale biogas production. High dust concentrations were identified in the pig barns, especially during the feeding and manure cleaning events inside the farrowing and weaning barns with slatted floors. Inhalable dust ranged from 0 mg/m$^3$ to 12.45 mg/m$^3$, while the allowable dust ranged from 0 mg/m$^3$ to 9.62 mg/m$^3$. Ammonia concentration ranged from 0 ppm to 20 ppm (1 ppm = 1 cm$^3$/m$^3$), and the carbon dioxide concentration ranged from 300 ppm to 8 000 ppm. The highest ammonia concentration was recorded in the fattening barn during the summer season, while the highest carbon dioxide concentration was reported in the weaning barn during the summer season. The results of this study were similar to the results of studies performed on pig farms under natural and mechanical ventilation systems. On the other hand, the problems encountered during the gas measurements on the pig farm were directly related to the inadequate housing layout due to the obstruction of windows, fans and air channels for indoor ventilation, and thus the measurement devices faced harsh working conditions. Therefore, it is recommended that the housing system should be improved with repaired windows and curtains especially for the winter season; similarly, the repair of the fans should be attempted in order to improve the ventilation, especially in the gestation barns.

**Keywords:** pig farm, aerial pollutant, barn, China, gases, dust
**DOI:** 10.3965/j.ijabe.20130601.003

**Citation:** Mendoza Huaitalla R, Gallmann E, Liu X J, Hartung E. Aerial pollutants on a pig farm in peri-urban Beijing, China. Int J Agric & Biol Eng, 2013; 6(1): 36－47.

## 1 Introduction

China is the largest pig production country in the world, with approximately 50% of the world’s pig output[1]. The fast development of livestock farms has brought environmental burdens through the accumulation of animal waste and it has especially increased the problems of air pollution in the animal buildings, affecting both human and animal health and welfare[2,3]. In fact, indoor/outdoor air quality on animal farms has declined and it is currently far beyond the thresholds established by the health standards for livestock and farmers[3]. Ammonia ($NH_3$) is mainly produced by the microbial activity in the breakdown of urea in the pig urine, while the carbon dioxide ($CO_2$) concentration is the result of the energy metabolism rate in animals and their manure production[4], reflected as the animal respiration[5]. Additionally, particulate matter (PM) or dust particles can penetrate into the deeper respiratory airways,

**Received date:** 2011-11-09 **Accepted date:** 2013-03-11
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compromising animals' and human's respiratory health. The generation of PM, its suspension in the air and its release outside the pig facilities depends on the type of housing, management, husbandry techniques, feeding, pig stage, and environmental factors related to the climatic conditions[6]. The size of the dust particles varies from less than 0.1 micron (μm) to over 100 μm. The European Committee for Standardization classifies the airborne particles in workplace atmospheres in three different fractions[7]: $PM_{100}$ or inhalable fraction (the mass fraction of particles which can be inhaled through the nose or mouth); $PM_{10}$ or thoracic fraction (the mass fraction of particles that passes the larynx); and $PM_4$ or respirable fraction (the mass fraction of particles that reaches the alveoli). Therefore, the smaller the particles or fractions (i.e., $PM_{2.5}$, $PM_1$), the deeper they can penetrate and deposit into the respiratory tract.

Last but not the least, China is divided into six pig production zones: Middle and lower reaches of the Yangtze River, North China, Northeast China, Southeast China, municipalities such as Beijing, Tianjin and Shanghai, and other 10 provinces[8]. In Beijing, the Shunyi District represents a significant share (43%) of Beijing's total pig production and it is well-placed as the dominant region in animal husbandry[9].

The overall objectives of this paper are: 1) To present measurement results of the concentrations of gases, i.e., $NH_3$, $CO_2$, and PM of a pig farm located in the Shunyi district in Beijing, China; 2) To compare the results with published studies performed on pig farms with natural and mechanical ventilation systems.

It should be noted that the measurements were mainly performed in naturally ventilated barns; hence, inadequacy due to air leakage and surface absorption of gases should be taken into consideration.

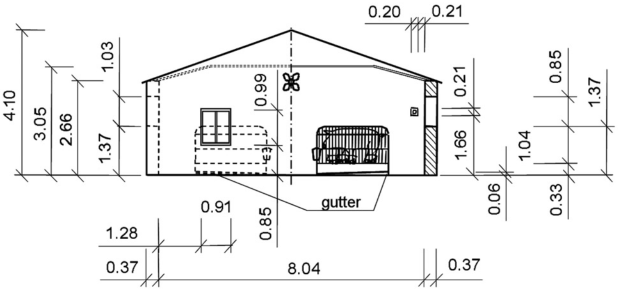
## 2 Materials and methods

### 2.1 Pig farm

A pig farm located in the peri-urban area of Beijing was used as the research location. The pig farm was characterized by the manure management system denominated "gan qing fen" or dry cleaning of the manure, in which the pig manure was manually collected twice a day.

Farrowing and gestating sows received two portions of wet feed daily (restricted feeding). Weaning piglets and fattening pigs received ad lib feeding, weaners were fed with pellets, and fattening pigs with dry meal. The watering regime was basically ad lib (unrestricted access). Pig diets consisted of corn, wheat, soybean meal, fish powder, compound premix, and lysine. Refer to a previous study for further detailed descriptions[1].

The pig barns taken as sampling places in this study and their dimensions were plotted by iGrafx Designer v1.0 software. Figures 1-3 are intended to illustrate the typical arrangements of the pig barns at the different pig stages. Table 1 presents a general description of the pig farm researched. Partition walls in both the weaning and farrowing buildings divided the pig barn into three and two identical rooms, respectively. The farmer's room was found right next to the pig barns and is not shown in the figures below. The gestation barn and the fattening pig barn were of similar dimensions; thus it is not presented in the figures.



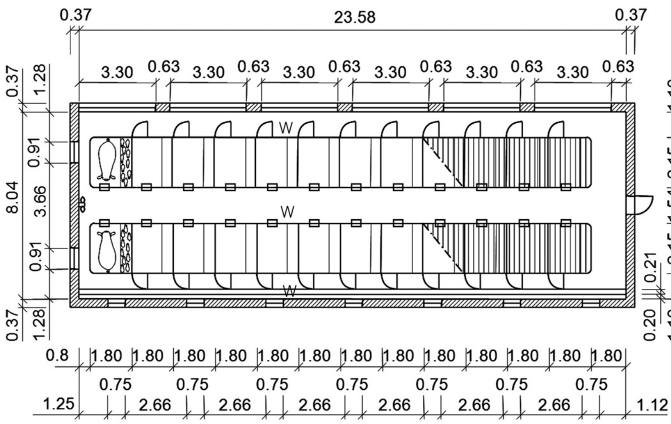




Figure 1 Layout of a farrowing pig barn with slatted floor

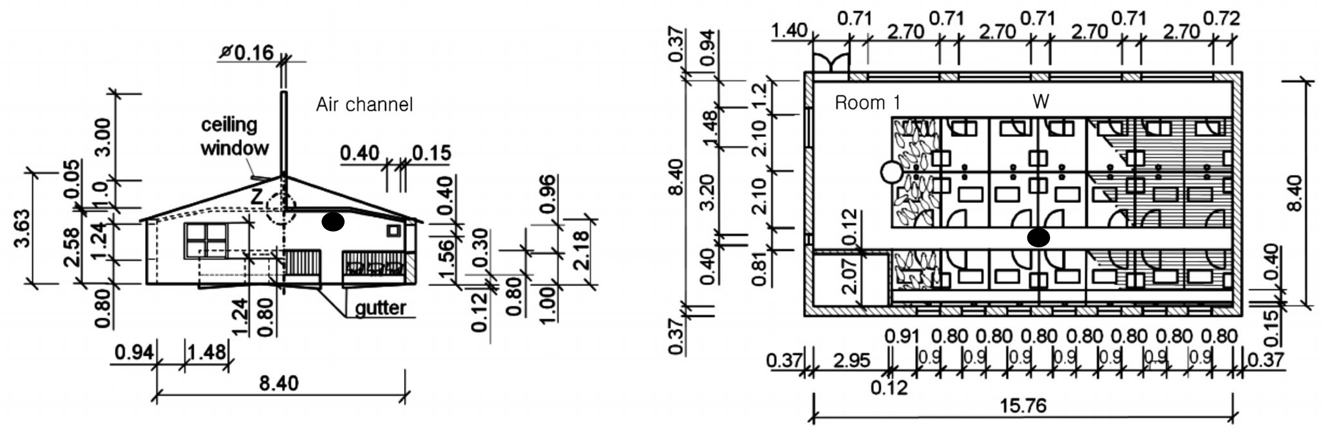
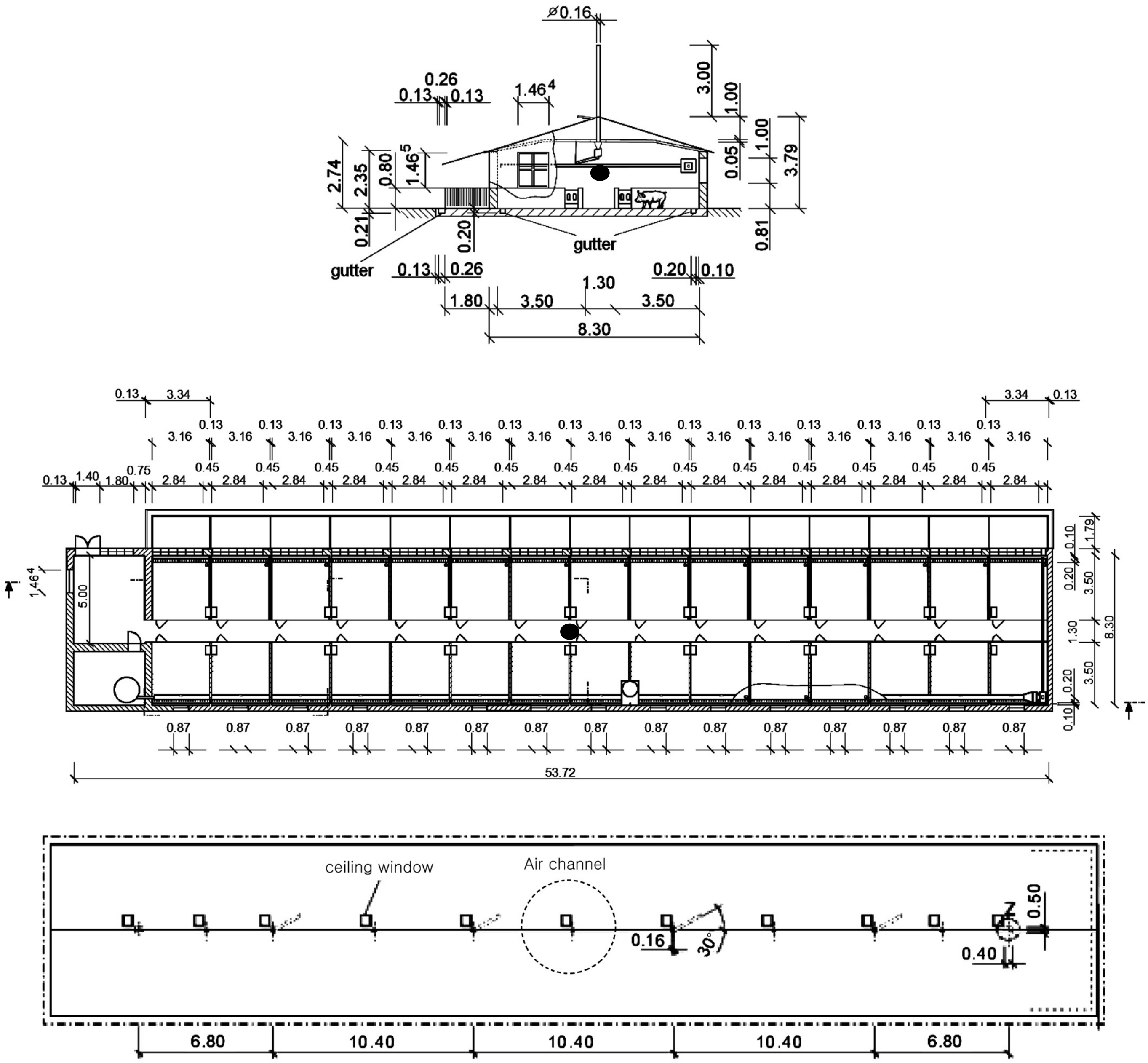



Figure 2 Layout of a weaning pig barn with slatted floor




Legends:

● Dust and gas sampling location W Walkway ⊟ Window

Figure 3 Layout of a fattening pig barn with concrete floor (the dotted circle shows an air channel on the double ceiling of the barn)

**Table 1 Pig farm description**

| Pig stage | No. barns | Max. cap. pig/barn | Capacity pig/pen | Feeding regime | Ventilation (status) | Ventilation summer | Ventilation winter | Barn floor | Outdoor area | Dimensions (L×W×H) |
|---|---|---|---|---|---|---|---|---|---|---|
| Gestation | 20 | 70 | 1-2 | wet meal | mechanical (inop.) | windows/doors | scarce | concrete | no | 54 m×8 m×4 m |
| Farrowing | 8 | $200^p$-$20^s$ | 1 | dry meal creep feed | mechanical (inop.) | windows/doors | scarce | slats | no | 24 m×8 m×4 m |
| Weaning | 3 | 200 | 10-16 | pellets | natural | windows/doors/channels | scarce | concrete/slats | no | 16 m×8 m×4 m |
| Fattening | 25 | 300 | 10-14 | dry meal | natural | windows/doors/channels | scarce | concrete | yes | 54 m×8 m×4 m |

Note: Adapted from a previous publication[1]; $^p$: piglet; $^s$: sow; cap.: capacity; inop.: inoperative. L: Length, W: Width, H: Height.

**Table 2 Devices used in this study**

| Item | Device principle | Measuring range | Resolution | Sampling period | Sampling rate | Device employed |
|---|---|---|---|---|---|---|
| $NH_3$ | Color diffusion tube | 0.25-3 ppm, 2-30 ppm | ± 10%-15% | 17 h in one day (Aug 2010) | 1 h | Dräger tubes |
| | Electro-chemical sensor | 0-300 ppm | ± 1 ppm | Summer: Jun-Aug 2010<br>Winter: Dec-Jan 2010 | 30 s | Dräger Multiwarn II |
| $CO_2$ | Color diffusion tube | 100-3000 ppm | ± 10%-15% | 17 h in one day (Aug 2010) | 1 h | Dräger tubes |
| | Infra-red sensor | 0-5% Vol. | ± 0.01 Vol. | Summer: Jun-Aug 2010<br>Winter: Dec-Jan 2010 | 30 s | Dräger Multiwarn II |
| $PM_{10-1}$ | Light-scattering photometer | 0.001-100 mg/m$^3$ | ± 0.001 mg/m$^3$ | Summer: May-Aug 2010<br>Winter: Dec 2010 | 5 s | DustTrak$^{TM}$ Aerosol Monitor |

The workers in the gestation and fattening barns used a shovel in order to collect the pig manure from the concrete floors and flushed the pigsties with water. Afterwards urine and the rest of the manure flowed through the urine gutters. On the contrary, in the weaning and farrowing barns with slatted floors, the pig manure was cleaned by dry sweeping, urine and some manure remains dropped through the slats and were discharged by gravity to the external channel in the direction of the biogas installation.

### 2.2 Materials

The main devices and sensors used in this study are described in Table 2 and as follows:

1) Color diffusion tubes (Dräger tubes) for $CO_2$ and $NH_3$, and a gas detector pump were used according to the manufacturer's instructions[10]. Each tube contained a very sensitive reagent (calibrated to a particular gas) that reacted with a coloration change after pumping and delivering the correct volume of air through the tube[11].

2) A portable gas measuring device (Dräger Multiwarn II) was used for $CO_2$ and $NH_3$ gas measurements, and the Dräger GasVision v4.5 software for on-site data evaluation. An infrared sensor (absorption cell) for $CO_2$, that measures infrared (IR) light radiating from objects in its field of view[12]. An electro-chemical sensor for $NH_3$, that operates by reacting with the gas of interest and produces an electrical signal proportional to the gas concentration[13].

3) A dust measuring instrument (DustTrakTM Aerosol Monitor) consisting of a light scattering photometer that measures the PM concentration. The instrument can detect particles by measuring the total amount of light they scatter based on the principle of the infrared light emitted by a Ga-As (Gallium Arsenide) laser diode. The intensity of light scattered by a particle is a function of the particle size, shape and index of refraction[14,15]. The data was downloaded and pre-evaluated by TrakPro v3.33 software.

The photometer and the portable gas measuring device were calibrated.

### 2.3 Methods

Table 2 shows the time intervals at which the measurements were performed (see sampling period and sampling rate). In general, sampling was conducted at each pig stage. The air was pumped at about 1 m above the ground inside the pig barns for the color diffusion tubes. The devices were also installed at about 2 m height in the center of the barn. Selection of the central sampling location to represent the barn gas concentration was based on the results of Dong et al.[16].

### 2.4 Statistical analysis

The raw data were exported to the OriginPro v8.5 software (OriginLab Corporation, USA) for statistical analyses. Some datasets in the gases' concentrations are not presented in this paper due to inconsistent results caused by numerous mechanical problems during the summer and winter sampling months. The data selected were presented in descriptive forms and subjected to mean, maximum, minimum, and coefficient of variation. The PM datasets were tested for normality using the Kolmogorov-Smirnov ($p < 0.05$). In order to detect significant difference between the means among various measurement sites, analysis of variance (ANOVA) and Tukey test of significance ($p < 0.05$) were utilized when the data were normally distributed.

## 3 Results and discussion

### 3.1 Concentrations of gases by the color diffusion tubes

The means of $NH_3$ and $CO_2$ concentration from the four pig barns are presented in Tables 3 and 4, respectively. Daily average concentration of $NH_3$ and $CO_2$ in the weaning barn was higher ($NH_3$: 1.8 ppm; $CO_2$: 841 ppm) than in the other barns, and it was followed by the gestation barn. On the contrary, the levels of $NH_3$ and $CO_2$ were the lowest inside the farrowing (1.1 ppm) and gestation barns (609 ppm), respectively.

Table 5 shows that events such as feeding and resting presented markedly different gas concentrations. During the feeding events, the $CO_2$ concentration surpassed 1 000 ppm in most cases, and during the resting/sleeping events, its value was lower than 1 000 ppm. Interestingly, it was observed that the $NH_3$ concentrations before the cleaning of the floors (19 June 2010) were from 2 ppm (gestation) to 12 ppm (weaning), while the $NH_3$ concentrations dropped to 1 ppm (gestation) and to 5 ppm (weaning) after cleaning the floors. Therefore, it can be inferred that the animal activity and events such as manure removal exert an effect in the daily concentrations of gases, as found by several authors in similar studies[5-6,8-17]. $NH_3$ and $CO_2$ concentrations from gestation and farrowing were different than the weaning and fattening concentrations of gases. It seems that there may be an association between these two groups. A similar association was found during the study of the pig manures originating from the same pig farm; the results are presented in a previous publication[1].

**Table 3 $NH_3$ concentrations monitored during the day (ppm)**

| Ammonia ($NH_3$) | Gestation | Farrowing | Weaning | Fattening |
|---|---|---|---|---|
| Max (ppm) | 3.13 | 2.94 | 3.10 | 3.10 |
| Min (ppm) | 0.67 | nd | 0.90 | 0.45 |
| Mean whole day (ppm) | 1.73 | 1.13 | 1.80 | 1.13 |
| Mean before noon (ppm) | 1.87 | 0.80 | 1.85 | 1.63 |
| Mean after noon (ppm) | 1.65 | 1.31 | 1.77 | 0.85 |
| No. sows | 84 | 24 | 0 | 0 |
| No. pigs or piglets | 0 | 80 | 200 | 100 |

nd means not detected.

**Table 4 $CO_2$ concentrations monitored during the day (ppm)**

| Carbon dioxide ($CO_2$) | Gestation | Farrowing | Weaning | Fattening |
|---|---|---|---|---|
| Max (ppm) | 727.27 | 1000.00 | 1500.00 | 1000.00 |
| Min (ppm) | 545.45 | 400.00 | 600.00 | 450.00 |
| Mean whole day (ppm) | 609.43 | 663.64 | 841.18 | 632.35 |
| Mean before noon (ppm) | 563.64 | 675.76 | 700.00 | 541.67 |
| Mean after noon (ppm) | 632.32 | 657.58 | 918.18 | 681.82 |
| No. sows | 84 | 24 | 0 | 0 |
| No. pigs or piglets | 0 | 80 | 200 | 100 |

**Table 5 Concentrations of gases in the pig barns based on different daily events**

| Day and time | Pig stage | No. pigs | $CO_2$ (ppm) | $NH_3$ (ppm) | Event |
|---|---|---|---|---|---|
| 10 June 2010 11:00 a.m. | G | 55 | 600 | 2.0 | after rainfall/sows resting |
| | F | 24°, 213* | 1100 | 5.0 | after rainfall/sows resting |
| | W | 191 | 1800 | 6.0 | after rainfall/piglets resting |
| | T | 281 | 700 | 1.0 | after rainfall/pigs eating |
| 17 June 2010 2:00 p.m. | G | 66 | 600 | 1.5 | after rainfall/farmer cleaning floors |
| | F | 24°, 60* | 800 | 1.0 | after rainfall/sows resting |
| | W | 270 | 900 | 2.0 | after rainfall/farmer cleaning floors |
| | T | 39 | 600 | 1.5 | after rainfall/farmer cleaning floors |

| Day and time | Pig stage | No. pigs | $CO_2$ (ppm) | $NH_3$ (ppm) | Event |
|---|---|---|---|---|---|
| 19 June 2010 7:00 a.m. | G | 44 | 800 | 2.5 | before cleaning floors/sows waiting for first meal |
| | F | 22°, 80* | 1200 | 2.0 | before cleaning floors/piglets suckling |
| | W | 290 | $3000^{+}$ | 12.0 | before cleaning floors/piglets eating |
| | T | 205 | 1000 | 2.0 | before cleaning floors/pigs eating/playing |
| 19 June 2010 8:00 a.m. | G | 44 | 600 | 1.0 | after cleaning floors/sows resting |
| | F | 22°, 80* | 1000 | 1.5 | after cleaning floors/sows sleeping/eating |
| | W | 290 | 2000 | 5.0 | after cleaning floors/piglets resting/eating |
| | T | 205 | 800 | 2.0 | after cleaning floors/pigs resting/eating |
| 21 June 2010 1:00 p.m. | G | 70 | 800 | 1.0 | sows eating/resting |
| | F | 22°, 90* | 1000 | 0.5 | sows resting/piglets suckling |
| | W | 290 | 1300 | 3.0 | piglets eating/playing/resting |
| | T | 205 | 1300 | 4.0 | pigs eating/playing/resting |
| 24 June 2010 11:00 a.m. | G | 70 | 600 | 1.8 | sows resting/no feed available |
| | F | 22°, 160* | 1000 | 1.0 | sows resting/piglets suckling |
| | W | 55 | 800 | 1.9 | piglets resting/eating |
| | T | 248 | 900 | 2.5 | pigs resting/eating |
| 28 June 2010 2:00 p.m. | G | 70 | 800 | 1.0 | sows sleeping |
| | F | 23°, 230* | 1000 | 0.3 | sows sleeping/piglets suckling |
| | W | 175 | 600 | 0.8 | piglets sleeping/eating |
| | T | 220 | 1400 | 1.8 | pigs playing/farmer cleaning the floors |
| 30 June 2010 9:00 a.m. | G | 58 | 800 | 1.8 | sows sleeping |
| | F | 23°, 230* | 1110 | 2.0 | sows awake/piglets suckling |
| | W | 273 | 700 | 1.8 | piglets sleeping |
| | T | 220 | 900 | 3.0 | pigs sleeping/eating |
| 06.July 2010 10:00 a.m. | G | 51 | 600 | 0.1 | sows sleeping |
| | F | 23°, 230* | 1400 | 2.1 | castration of piglets/piglets and sows awake |
| | W | 247 | 850 | 2.0 | piglets sleeping/eating |
| | T | 220 | 900 | 2.0 | pigs sleeping/eating/playing |

Note: ° sows; * piglet; $^{+}$ higher conc., G: gestation; F: farrowing; W: weaning; T: fattening.

### 3.2 Concentrations of gases by the portable gas monitor

Tables 6-7 and Figures 5-6 summarize the $CO_2$ and $NH_3$ concentrations measured during the summer and winter measurement periods in the pig barns. During the summer season, the $CO_2$ concentration was in the range of 300-1 500 ppm, and the daily mean concentration was 588 ppm, which met the Chinese Standard NY/T 388-1999 "Environmental quality standard for livestock and poultry farms"[18], that indicated an average $CO_2$ concentration of 819 ppm for pig farms from China. The weaning barn with slatted floor (WSF) presented higher $CO_2$ concentrations (100-1 500 $CO_2$ ppm) than the weaning barn with concrete floor (WCF) (300-500 ppm $CO_2$). This might be due to the better aeration observed in the WFC (Figure 4). The WSF showed windows distributed along the sidewalls of the barn, while the WFC lacked one sidewall and thus allowed higher air circulation; hence it is inferred that the $CO_2$ concentration was the result of this effect.

**Table 6 Concentrations of gases in the pig barns during the summer season**

| Gas | Subject measured | Gestation | Farrowing | Weaning (CF) | Weaning (SF) | Fattening |
|---|---|---|---|---|---|---|
| $NH_3$ (ppm) | Min | 0.00 | nd | 0.00 | 0.00 | 0.00 |
| | Max | 19.20 | nd | 0.83 | 0.87 | 7.83 |
| | Mean | 0.52 | - | 0.01 | 0.00 | 0.13 |
| | CV (%) | 369 | - | 981 | 2129 | 490 |
| $CO_2$ (ppm) | Min | 300 | 300 | 300 | 600 | 300 |
| | Max | 1 400 | 1 100 | 900 | 1 500 | 1 500 |
| | Mean | 423.00 | 510.53 | 431.07 | 1065.57 | 512.55 |
| | CV (%) | 34 | 45 | 29 | 14 | 31 |
| | No. sampling days | 6 | 3 | 6 | 1 | 5 |
| | No. pigs (average) | 60 | 230 (s), 23 (p) | 247 | 290 | 260 |

Notes: nd: not detected; -: not applicable; s: sow; p: piglet; CF: concrete floor; SF: slatted floor.

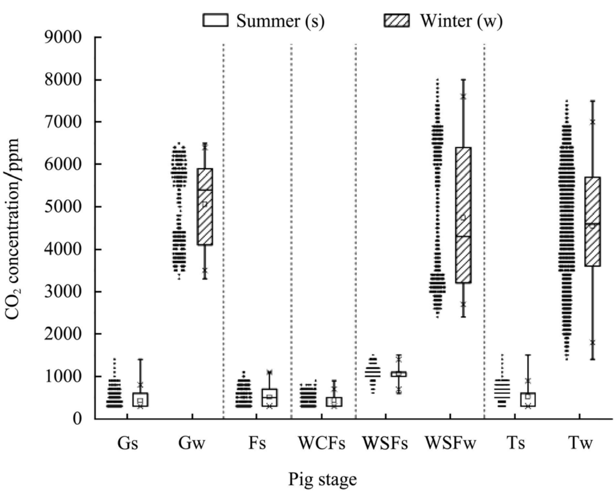
**Table 7 Concentrations of gases in the pig barns during the winter season**

| Gas | Subject measured | Gestation | Farrowing | Weaning (CF) | Weaning (SF) | Fattening |
|---|---|---|---|---|---|---|
| $NH_3$ (ppm) | Min | 0.00 | na | Na | 0.00 | 0.00 |
| | Max | 10.80 | na | Na | 7.70 | 20.20 |
| | Mean | 1.15 | na | Na | 0.30 | 2.09 |
| | CV (%) | 167.36 | na | Na | 322.04 | 185.00 |
| $CO_2$ (ppm) | Min | 3 300 | na | Na | 2 400 | 1 400 |
| | Max | 6 500 | na | Na | 8 000 | 7 500 |
| | Mean | 5 056.03 | na | Na | 4 740.52 | 4 549.14 |
| | CV (%) | 19.24 | na | Na | 34.10 | 30.46 |
| | No. sampling days | 2 | na | Na | 5 | 11 |
| | No. pigs (average) | 70 | na | Na | 300 | 300 |

Notes: na: not available; -: not applicable; s: sow; p: piglet; CF: concrete floor: SF: slatted floor.

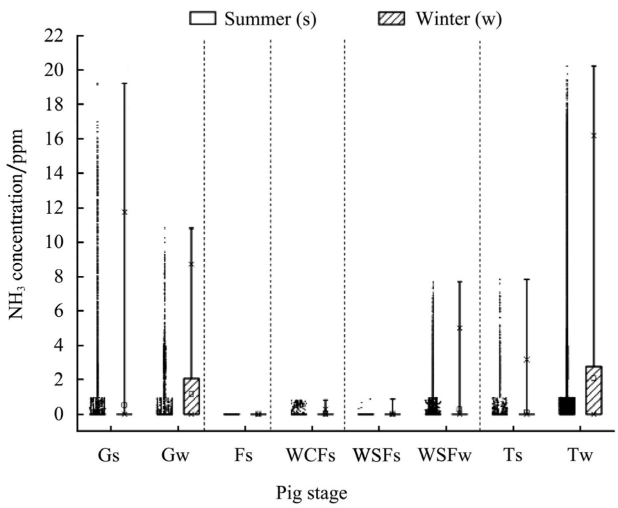
The farrowing and weaning CF barns were mainly empty during the winter season, therefore it was not possible to perform measurements of the gases in these barns.

Figure 4 View of the absence of a sidewall in the weaning barn with concrete floor (WCF)




Note: Gestation (G); Farrowing (F); Weaning Concrete Floor (WCF); Weaning Slatted Floor (WSF); Fattening (T)

Figure 5 $CO_2$ concentration in the pig barns during the summer and winter season




Note: Gestation (G); Farrowing (F); Weaning Concrete Floor (WCF); Weaning Slatted Floor (WSF); Fattening (T)

Figure 6 $NH_3$ concentration in the pig barns during the summer and winter season

The $CO_2$ mean concentration during the winter season (-20℃ to 10℃ ambient temperature in Shunyi, Beijing) was in the range from 1 400 to 8 000 ppm, which surpassed the Chinese threshold (819 ppm).

One explanation of the high $CO_2$ concentration might be due to the lack of air exchange inside the pig barns, since plastic sheets and amendments are arranged on the sidewalls, windows, doors, and air channels in order to maintain the indoor heating, as presented in Figure 7.

Peaks in the $NH_3$ concentrations (up to 18 ppm) were repeatedly observed in the mornings at 6 a.m. (Figure 8), which might be related to the excretion pattern of the pregnant sows after their first feeding time at 4-5 a.m.

Figure 7 Weaning barn during winter (left); farmer covering the windows with plastic sheets (right)

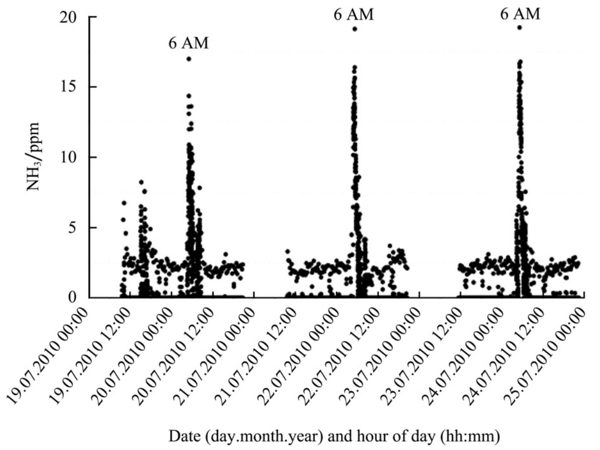



Figure 8 $NH_3$ concentration in a gestation pig barn during the summer measurements

### 3.3 Particulate matter concentration by the aerosol monitor

The results of the measurements of the PM in the different sampling places are presented in Table 8 and Figures 9-13. The highest concentrations for $PM_{10}$ and $PM_1$ in the weaning barn were 7.52 mg/m$^3$ and 9.62 mg/m$^3$, respectively, while the highest $PM_{2.5}$ was identified in the fattening barn (4.49 mg/m$^3$). Significant differences among the PM concentrations were found in the places measured by the Tukey test of significance at $p < 0.05$.

It was found when analyzing the diurnal course of the PM concentrations (Figure 13, left) that the aerial $PM_{10}$ concentration was below 1.5 mg/m$^3$ in the farrowing and gestation barns (gestation results are not shown), and no strong diurnal variation in the PM concentrations was shown; this might be related to the dust generation being low as the feeding rations for sows were mainly wet meals.

On the contrary, two peaks of the indoor $PM_{10}$ concentration were observed in the weaning and fattening barns (farrowing results are not shown) which might be related to the cleaning and feeding events at about 6-7 a.m. and 3-6 p.m., respectively (Figure 13, right).

**Table 8 Particulate matter concentrations in the pig barns during the summer and winter seasons**

| | Gestation | Farrowing | Weaning (CF) | Weaning (SF) | Fattening | Fattening * | Outside fat. | Empty barn | Farmer's room |
|---|---|---|---|---|---|---|---|---|---|
| $PM_{10}$ | | | | | | | | | |
| Max (mg/m$^3$) | 5.88 | 2.26 | 1.81 | 7.52 | 7.50 | 12.45 | 1.12 | 1.32 | 1.93 |
| Min (mg/m$^3$) | 0.09 | 0.08 | 0.05 | 0.09 | 0.02 | 0.03 | 0.00 | 0.34 | 0.02 |
| Mean±SD (mg/m$^3$) | 0.29±0.17$^a$ | 0.46±0.28$^b$ | 0.24±0.15$^c$ | 0.83±0.69$^d$ | 0.98±0.47$^e$ | 0.65±0.42$^f$ | 0.08±0.08$^g$ | 0.46±0.08$^h$ | 0.14±0.10$^b$ |
| CV (%) | 58 | 62 | 64 | 83 | 48 | 64 | 93 | 17 | 71 |
| $PM_{2.5}$ | | | | | | | | | |
| Max (mg/m$^3$) | 0.74 | 1.22 | 0.97 | 1.31 | 4.49 | 5.27 | 0.72 | 0.66 | 0.55 |
| Min (mg/m$^3$) | 0.08 | 0.12 | 0.18 | 0.13 | 0.06 | 0.00 | 0.00 | 0.16 | 0.02 |
| Mean±SD (mg/m$^3$) | 0.21±0.10$^a$ | 0.45±0.14$^b$ | 0.23±0.02$^c$ | 0.29±0.09$^d$ | 0.22±0.10$^a$ | 0.47±0.22$^e$ | 0.40±0.22$^f$ | 0.37±0.10$^g$ | 0.09±0.05$^h$ |
| CV (%) | 48 | 31 | 11 | 31 | 45 | 47 | 55 | 28 | 53 |
| $PM_1$ | | | | | | | | | |
| Max (mg/m$^3$) | 1.09 | 2.15 | 1.53 | 9.62 | 6.22 | 4.93 | 0.47 | 0.31 | 2.56 |
| Min (mg/m$^3$) | 0.01 | 0.02 | 0.15 | 0.06 | 0.12 | 0.01 | 0.16 | 0.10 | 0.09 |
| Mean±SD (mg/m$^3$) | 0.25±0.09$^a$ | 0.15±0.08$^b$ | 0.24±0.04$^c$ | 0.35±0.26$^d$ | 0.35±0.16$^e$ | 0.42±0.23$^f$ | 0.25±0.04$^g$ | 0.21±0.05$^h$ | 0.14±0.04$^i$ |
| CV (%) | 35 | 51 | 17 | 75 | 45 | 55 | 15 | 26 | 27 |
| No. sampling days | 4 | 4 | 2 | 4 | 4 | 4 | 2 | 2 | 2 |

Notes: *Measurements performed during Winter Season. Means followed by different lower case letters (a, b, c, etc.) are significantly different from each other by the Tukey Test ($p < 0.05$); CF: concrete floor; SF: slatted floor; Fat.: fattening.

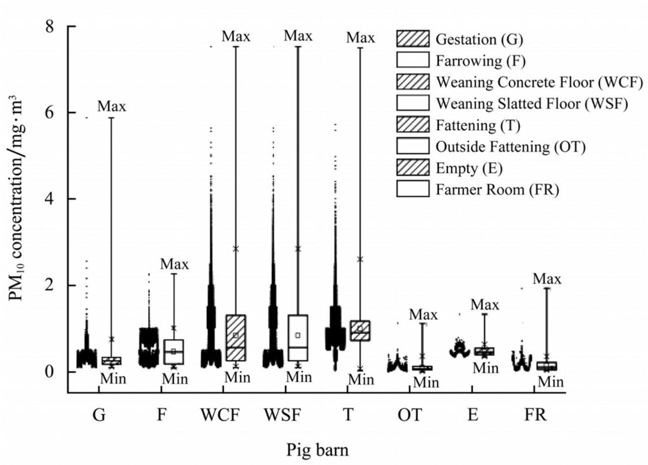



Figure 9 $PM_{10}$ concentrations in the different sampling places

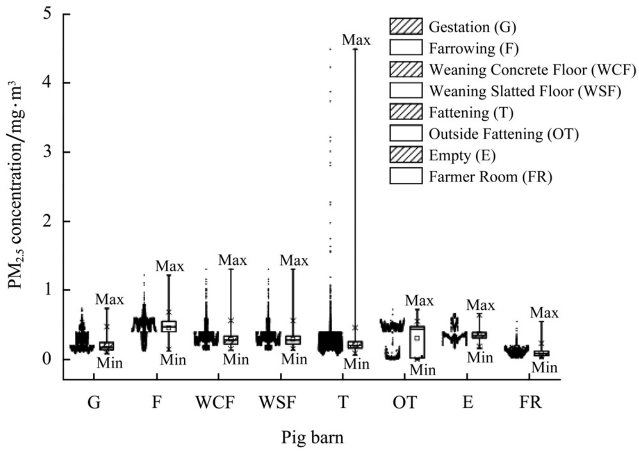



Figure 10 $PM_{2.5}$ concentrations in the different sampling places

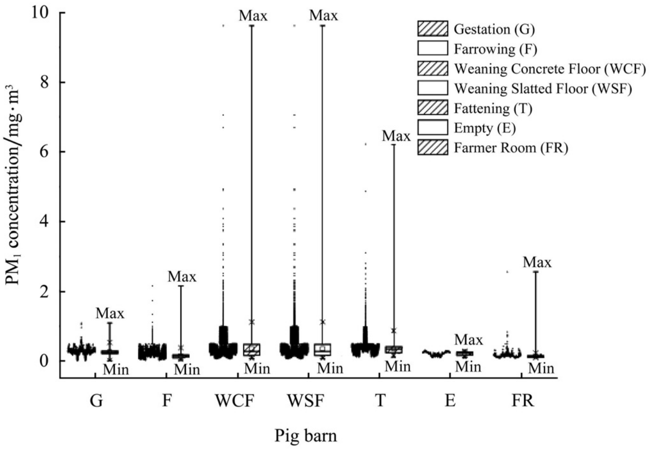



Figure 11 $PM_1$ concentrations in the different sampling places

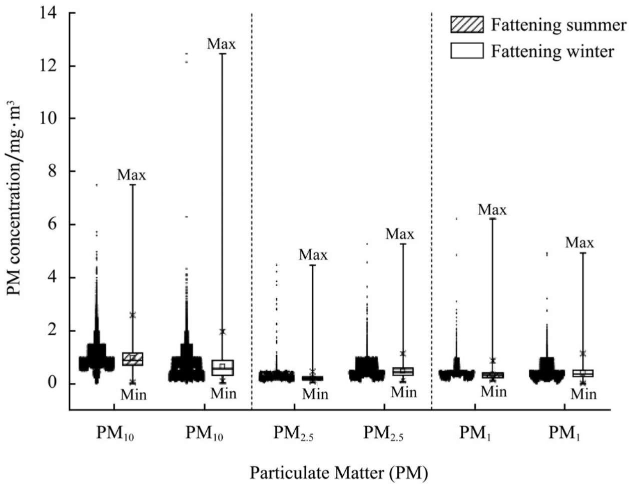



Figure 12 $PM_{10\text{-}1}$ concentrations in the different sampling places

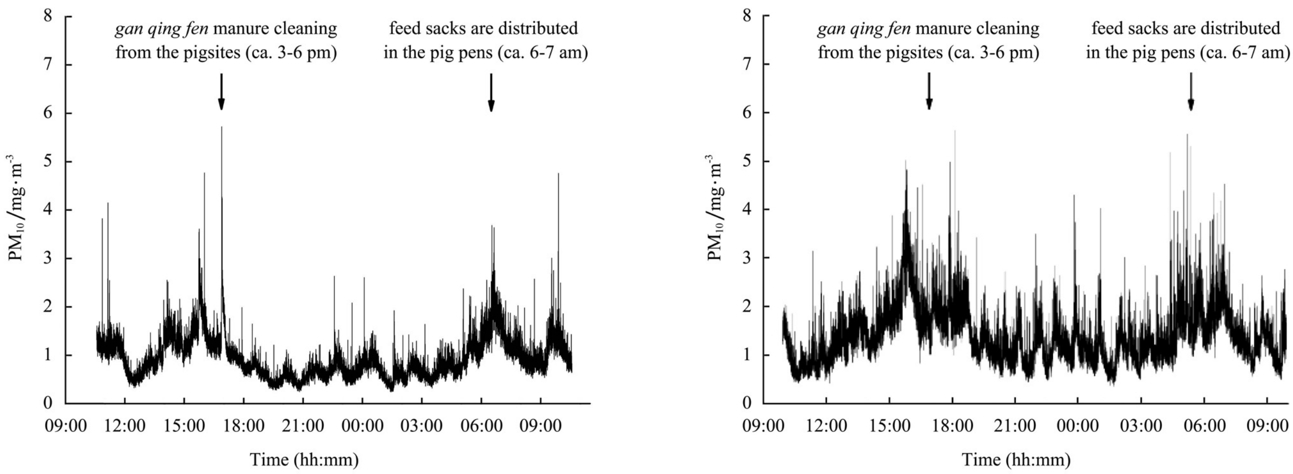



Figure 13 $PM_{10}$ diurnal concentrations in a farrowing (left) and weaning barn with slatted floor (right)

It is interpreted from the figures above that the farmers might be exposed to high $PM_{10}$ concentrations (more than 4 mg/m$^3$) at least five hours a day, which is the average time required to complete the feeding and manure removal tasks under the “gan qing fen” system. In fact, the $PM_{10}$ concentrations surpassed the $PM_{10}$ Chinese threshold of 1 mg/m$^3$[18]. This finding is especially observed inside the weaning and fattening barns, as the ad lib feeding system is based on dry meals.

## 4 Comparison with published literature

Tables 9-11 compile the results obtained in $NH_3$, $CO_2$ and PM concentrations in different pig stages from studies performed with diverse techniques. The results of this study are similar to those obtained in the investigations reviewed.

**Table 9 Comparison of selected publications with the results of this study (Part I)**

| Pig Stage | Vent. system | Device type | Particularity | Reported conc. (ppm) | | Particulate matter (mg/m³) | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $NH_3$ | $CO_2$ | $PM_{100}$ | $PM_{10}$ | $PM_{2.5}$ | $PM_1$ | |
| Gestation | M | Portable gas monitor† | Winter and summer | 0.84 | 2 739.50 | | 0.29 | 0.21 | 0.25 | This study |
| Farrowing | M | | | nd | 511.00 | | 0.46 | 0.45 | 0.15 | |
| Weaning | N | | | 0.16 | 2 079.33 | | 0.54 | 0.26 | 0.30 | |
| Fattening | N | | | 1.11 | 2531.00 | | 0.82 | 0.35 | 0.39 | |
| Gestation | M | Dräger colorimetric tubes† | Summer | 1.73 | 609.43 | | | | | |
| Farrowing | M | | | 1.13 | 663.64 | | | | | |
| Weaning | N | | | 1.80 | 841.18 | | | | | |
| Fattening | N | | | 1.13 | 632.35 | | | | | |
| Breeding | N | Dräger colorimetric tubes† | | 0.33 | 648.00 | 0.15 | | 0.12 | | [5] |
| Farrowing | N | | | 0.88 | 704.00 | 0.23 | | 0.08 | | |
| Nursing | N | | | 2.32 | 720.67 | 0.34 | | 0.13 | | |
| Growing | N | | | 2.48 | 694.33 | 0.28 | | 0.15 | | |
| Finishing | N | | | 3.82 | 773.00 | 0.21 | | 0.24 | | |
| Grower/Finisher | N | Photoacustic multigas analyzer† | Spring | 7.79 | 1 113.33 | | | | | [19] |
| | | | Summer | 8.98 | 780.30 | | | | | |
| Gestation | N | Air sampling bags† | | | 1 475.09 | | | | | [16] |
| Farrowing | N | | | | 2 854.13 | | | | | |
| Nursery | N | | | | 2 701.73 | | | | | |
| Grower/Finisher | N | | | | 1 806.59 | | | | | |

**Table 10 Comparison of selected publications with the results of this study (Part II)**

| Pig Stage | Vent. system | Device type | Particularity | Reported conc. (ppm) | | Particulate matter (mg/m³) | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $NH_3$ | $CO_2$ | $PM_{100}$ | $PM_{10}$ | $PM_{2.5}$ | $PM_1$ | |
| Grower/Finisher | M | Colorimetric tubes† | | 26.00 | 3 736.00 | 2.41 | | | | [20] |
| Finishing (A) | M | Sensidyne detector tubes† | | 6.71 | | | | | | [21] |
| Gestation | M | | | 11.00 | | | | | | |
| Farrowing | M | | | 3.86 | | | | | | |
| Finishing (B) | N | | | 11.14 | | | | | | |
| Nursery | M | | | 3.39 | | | | | | |
| Breeding | M | Test strips† | | 17.20 | | | | | | [22] |
| Gestation | N | | | 8.70 | | | | | | |
| Farrowing | M | | | 9.03 | | | | | | |
| Nurseries | M | | | 6.20 | | | | | | |
| Finishing | N | | | 19.10 | | | | | | |
| Finishing | M | Photoacoustic infrared $CO_2$ monitor† | Barn 1 | | 2 310.30 | | | | | [23] |
| | | | Barn 2 | | 2 040.00 | | | | | |
| Finishing | M¹ | Sensidyne detector tubes† | Control, no oil | 6.92 | | 3.51 | 3.14 | 0.25 | | [24] |
| | N² | Filters, dust samplers§ | Oil applied | 4.37 | | 1.23 | 0.80 | 0.07 | | |
| Grower/Finisher | M | Filter holders§ | Regular | | | | 2.48 | 0.28 | | [25] |
| | | | Regular, little straw | | | | 2.88 | 0.32 | | |
| | | | Free-range | | | | 3.64 | 0.39 | | |
| Finishing | M | Dräger tubes† | | 8.40 | | 3.90 | | | | [26] |
| | ACNV | Casella dust samplers§ | | 8.30 | | 4.10 | | | | |

**Table 11 Comparison of selected publications with the results of this study (Part III)**

| Pig Stage | Vent. system | Device type | Particularity | Reported conc. (ppm) | | Particulate matter ($mg/m^3$) | | | | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $NH_3$ | $CO_2$ | $PM_{100}$ | $PM_{10}$ | $PM_{2.5}$ | $PM_1$ | |
| Fattening | M | Infrared spectroscopy† | Fattening cycle 1 | 12.00 | 1 815.10 | | 0.31 | 0.10 | 0.13 | [17] |
| | | Aerosol monitor§ | Fattening cycle 2 | 7.70 | 1 509.50 | | 0.43 | 0.20 | 0.13 | |
| | | | Fattening cycle 3 | 6.40 | 1 126.50 | | 0.44 | | 0.11 | |
| | | | Fattening cycle 4 | 10.30 | 1 606.20 | | 0.60 | 2.50 | | |
| | N | Infrared spectroscopy† | Fattening cycle 1 | 9.90 | 727.90 | | 0.17 | 0.05 | 0.07 | |
| | | Aerosol monitor§ | Fattening cycle 2 | 6.00 | 625.80 | | 0.15 | 0.10 | 0.05 | |
| | | | Fattening cycle 3 | 7.60 | 648.10 | | 0.13 | | 0.07 | |
| | | | Fattening cycle 4 | 9.00 | 629.30 | | 0.19 | 0.06 | | |
| Sows | M | Chemiluminescence $NO_x$ analyzer and $NH_3$ convertor† | | 17.80 | | | 1.10 | 0.12 | | [27] |
| Weaners | M | Gravimetric filtration§ | | 4.60 | | | 3.40 | 0.30 | | |
| Fattening | M | | | 18.20 | | | 2.80 | 0.25 | | |
| Weaning | M | Stationary gas fiber filter§ | Control, no fat in feed | | | 3.59 | | 0.27 | | [28] |
| | | | In walkway | | | 1.97 | | 0.18 | | |
| | | | Above a pen | | | 3.88 | | 0.20 | | |
| | | Portable total dust sampler§ | Control, no fat in feed | | | 13.80 | | | | |
| | | | 4% fat in feed | | | 7.30 | | | | |
| Finishing | M | Stationary gas fiber filter§ | Control, no fat in feed | | | 1.99 | | 0.12 | | |
| | | | In walkway | | | 1.78 | | 0.10 | | |
| | | | Above a pen | | | 1.36 | | 0.10 | | |
| | | Portable total dust sampler§3 | Control, no fat in feed | | | 14.40 | | | | |
| | | | 4% fat in feed | | | 4.80 | | | | |

Notes: ACNV: Automatically controlled natural ventilation;
†: device used to measure concentrations of gases, §: device used to measure particulate concentration of matter;
M: mechanic, N: natural, $PM_{100}$: total dust; $PM_{10}$: inhalable dust; $PM_{2.5\text{-}1}$: respirable dust, Vent.: ventilation; nd: not detected;
1: cold weather; 2: warm weather; 3: portable device used by farmer.

## 5 Conclusions

It is concluded that the indoor environment of the pig farm presented airborne pollutants in high concentrations; although it complied with the international literature review, it is still far from the thresholds established in mainland China. Moreover, this study clearly showed that the problems encountered during the measurements of gases on the pig farm were directly related to the inadequate housing layout due to the obstruction of windows, fans and air channels for indoor ventilation.

## Acknowledgements

The authors would like to thank the International Research Training Group of the University of Hohenheim and the China Agricultural University for their supports. This study is part of the Sub Project 1.4 “Evaluation of nutrient and pollutant cycles of livestock production systems and manure management systems in the North China Plain”. The project is funded by the German Research Foundation (GRK 1070) and the Ministry of Education (MOE) of the People’s Republic of China. The authors also thank the fruitful cooperation with the Sino German Project: “Recycling of Organic Residues from Agricultural and Municipal Origin in China”, Sub Project 1: “Farm gate balance for animal production,” granted by the BMBF (FKZ 0330847A-H).

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