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CHARACTERISTICS OF HYDROGEN SULFIDE CONCENTRATIONS IN MECHANICALLY VENTILATED SWINE BUILDINGS

by

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Summary:

Hydrogen sulfide (H_2S) concentrations in two large, mechanically ventilated swine buildings (3B and 4B) were continuously measured with a fluorescence-based detector for six months. It was sampled 24 and 16 periods per day in pit headspaces, pit ventilation chimneys and wall ventilation fans. A total of 219 days of complete and reliable measurement data were selected to study the temporal and spatial variations of H_2S concentrations in the buildings. Average daily mean building H_2S concentrations were 167±21 and 232±39 ppb during the entire test for 3B and 4B, respectively. Seasonal variations of H_2S concentrations occurred as daily mean building concentrations ranged from 18 to 1,107 ppb. A saddle-shaped seasonal pattern from April to September was exhibited in 4B. Four diurnal patterns of H_2S concentrations were identified. Diurnal variation was correlated to ventilation that was influenced by diurnal outdoor temperature pattern over 90% of the time. The highest and lowest concentrations during fair weather occurred between 3:00-6:00 and 12:00-18:00, respectively. During the other days, the indoor H_2S concentration was inversely correlated to the airflow rate. Spatial concentration variations were also found. The daily mean concentration differences between any two sampling locations ranged from 20±6 to 132±17 ppb.

Keywords: Air quality, air pollution, environment, pig house, ventilation, temperature

INTRODUCTION

Hydrogen sulfide (H_2S) originates from the anaerobic fermentation of manure. High concentrations of H_2S are toxic to humans and animals. A concentration of 50 ppm can cause dizziness, irritation of the respiratory tract, nausea, and headache. Death from respiratory paralysis can occur with little or no warning in concentrations exceeding 1,000 ppm (Field, 1980). It has been responsible for many animal as well as human deaths (Field, 1980; Anonymous, 1996).

Usually, concentration of H_2S is very low in animal houses compared with other gases in swine buildings, like carbon dioxide (CO_2) and ammonia (NH_3). It was measured at 90 ppb in a normally ventilated confinement building and 280 ppb after the ventilation was shut off for six hours (Muehling, 1970). The H_2S concentration was 166 ppb in two naturally-ventilated swine houses during a 63-day measurement reported by Heber *et al.* (1997).

Although reports about acute H_2S concentration in swine houses were frequently found in the literature, most of the data were from short time and single spot measurements. The generation of H_2S in animal houses is affected by the manure production, temperature and other factors that are ever changing. The clearance of the gas from the houses is controlled by the ventilation system, which is usually designed to regulate indoor temperature. Seasonal and diurnal ambient temperature changes thus indirectly affect the evacuation of H_2S from the houses. Temporal variations of H_2S concentrations in swine houses therefore should exist. An animal house is an imperfectly mixed ventilation space, in which gas concentration gradients exist. Understanding of the temporal and spatial variations of H_2S concentration in swine houses is important for extending the knowledge of the behavior of this pollution gas and maintaining a healthier indoor environment for animals and workers.

The objective of this paper is to study variations of H_2S concentration measured in two mechanically ventilated swine buildings during six months. The specific objectives are to:

1) delineate seasonal variations of the H_2S concentrations and the factors that influenced these variations,
2) evaluate diurnal variations of the H_2S concentrations and different variation patterns, and
3) examine spatial variations of the H_2S concentrations at three sampling locations in the buildings.

EXPERIMENTAL PROCEDURE

Data presented in this paper were collected from two mechanically-ventilated, 1,000-pig finishing buildings involved in a large test of a new manure additive product. The two buildings (designated "3B" and "4B") were untreated. Ni *et al*. (1999) described the two buildings and the procedures related to H_2S measurement. A more detailed description of the test installation was given by Heber *et al*. (1998).

Air quality measurements during the additive test started on March 6 and ended on September 25, 1997. Because of problems with some software and hardware components including a lightning strike, there were days with incomplete data. To reduce errors in H_2S concentration investigation, only days with complete and reliable measurement were selected including 124 days in 3B and 95 days in 4B. March 18 and April 5 are the dates of first complete measurement for 3B and 4B, respectively. The last date of complete data is September 24 for 3B and September 25 for 4B. One day of complete measurement covers 24 hours of time.

Each day of data is divided into 24 or 16 periods. Each period had one data subset that consisted of H_2S concentrations sampled for 10 or 15 minutes at each location group. The other variables used in this paper included pig number, pig weight, airflow rate, indoor and outdoor temperatures. A total of 4,544 data subsets were used.

Hydrogen sulfide was measured with a SO_2 analyzer (Model 45, TEI, Inc.) after being converted to sulfur dioxide (SO_2) with an H_2S converter (Model 340, TEI, Inc., Mansfield, MA). It was sampled at three location groups: 1) pit headspace (six sampling points), 2) pit fans (four sampling points), and 3) end wall fans (five sampling points). Multiple sampling points of each location were connected in parallel to the gas sampling system (Figure 1).

At the beginning of the test, only groups 1 and 2 were connected. Gas at each location was sampled and measured continuously for 15 minutes before switching to another location group. Blocks of data were averaged and stored every 20 seconds. Thirty minutes were allocated during each 60-minute cycle to measure gas concentrations in each building. Thus, 24 sampling periods were obtained daily for gas concentrations at each location. From June 4 in 3B and from July 16 in 4B, gas location group 3 was added. With a sampling interval of 15 minutes, a 90-minute cycle was applied. Thus, 16 sampling periods were obtained daily. The sampling time for each location was reduced from 15 to 10 minutes on August 14. Thirty minutes every hour were allocated for each building and the number of sampling periods returned to 24 each day. The first 3-minute H_2S concentration data in the 15 and 10-minute measurements were ignored to allow the instruments to equilibrate. Thus, 12 or 7 minutes of useful gas concentration data were obtained in each period.

Pigs were weighed before entering the building. The average weight of the pigs before the first group reached the marketing weight was calculated based on the beginning weight and the number of days in the building. The pig growth rate was calculated according to the data from van Ouwerkerk and Aarnink (1992) for pigs with average growth rate of 0.75 kg/d. The recorded actual market weights of the pigs were also used to check and correct the pig weight in the building. The measurements in each building covered two partial pig growth cycles.

Building airflow was the sum of the airflow from the wall fans and the airflow from the pit fans. Airflow rates from the wall fans were calculated based on fan curves supplied by the manufacturer and the static differential pressure between indoor and outdoor air.

A full-size airflow rate sensor (FanCom Model FMS 50, Techmark, Lansing, MI) was installed inside each pit chimney below the ventilation fan for all the four pit chimneys in 4B. Airflow rate from pit ventilation was the sum of measured values by the four sensors. There was no airflow rate sensor installed for 3B. Airflow rates from the pit fans were estimated based on fan control voltage. The four chimney fans were controlled in parallel by a single speed controller. An airflow/voltage relationship was determined from other identical buildings that were equipped with pit fans operated at full speed most of the time during this test.

Air temperatures were measured with semiconductor sensors with stainless steel probes (Model AD592, Computer Boards, Inc., Mansfield, MA). Indoor temperatures measured at seven locations equally spaced along the center of each building length 2 m above the floor, and outdoor temperature were used in this paper.

Some definitions of mean concentrations were adopted to study the H_2S in different time durations and at different locations. An illustration is given in Table 1. The period mean (PM) is the mean concentration of the extracted 7 or 12 minutes continuous measurements taken every 20 seconds at each sampling location. The building concentration is the average of the PM concentrations at the three locations. When the concentrations at the wall fans were not available at the beginning of the test, the building concentration represented only the other two locations. The average period mean (APM) averages the PM concentrations at each sampling location or in the building that belong to the same period over a certain number of days. The daily means (DM) are the averages of the PM concentrations at each sampling location or in the building over one day's time. The average daily means (ADM) are the averages of the DM concentrations at each sampling location or in the building over more than one day, e.g. the entire test.

Table 1. Different mean concentrations used in this paper.

	Concentration at sampling locations			Building concentration
	Pit	Chimney	Wall fans	
Period mean (PM)	PM	PM	PM	PM
Average period mean (APM)	APM	APM	APM	APM
Daily mean (DM)	DM	DM	DM	DM
Average daily mean (ADM)	ADM	ADM	ADM	ADM

The investigation of the H_2S concentration characteristics in each building was conducted with the following steps:

1) Raw data from field tests were processed to obtain period means of the measured variables. Daily files with either 24 or 16 periods of data were generated. Pig numbers and average pig weights were incorporated into the relevant file.
2) Twelve graphs of H_2S concentration, temperature, airflow rate, etc. were printed for each day.
3) Days that consisted of 24 hours of good data were selected by visually inspecting the graphs and are referred to as “complete days”.
4) Daily means of H_2S concentrations and other variables were calculated for complete days to evaluate the seasonal variations. Days with different numbers of periods per day were processed together.

5) Graphs of complete days were visually classified according to the variation patterns of the outdoor temperature, H_2S concentration, and building airflow rate.
6) The classified daily files were processed by groups and analyzed statistically for diurnal variations. Days with 24 and 16 periods in a day were processed separately.
7) Data were further processed to obtain DM concentrations, ADM concentrations and other statistics.

RESULTS AND DISCUSSION

Overview of the Measurement Data

A total of 219 complete days consisting of a total of 4,554 sampling periods or data subsets were selected (Table 2). About 57% of the days of measurements were from 3B. Only six complete days were selected in 4B for July, because lightning damaged the ventilation data logging system. The selected data in 3B and 4B covers March 18 to Sept. 24 and April 5 to Sept. 25, respectively.

Table 2. Summary of data subsets.

	March	April	May	June	July	Aug.	Sept.	Total
Days								
Total	6	23	46	38	30	49	27	219
3B	6	9	21	20	24	28	16	124
4B	0	14	25	18	6 *	21	11	95
Data subsets								
Total	144	552	1104	616	480	1000	648	4544
3B	144	216	504	328	384	568	384	2528
4B	0	336	600	288	96	432	264	2016

* A lightning strike occurred in July causing a loss in data.

Avery *et al*. (1975) reported 80 spot measurement of H_2S concentrations in six swine houses using the methylene blue method. Heber *et al*. (1997) measured H_2S concentrations for 63 days from January to March with about 1,500 samples in each of the two naturally ventilated swine buildings. Measurements of H_2S concentrations for 89 days (from June to September) with 1,700 data subsets were presented by Ni *et al*. (1998). The duration of measurement, numbers of days and data subsets are much greater in this paper making this study the most comprehensive data set of H_2S concentration in swine buildings.

Overview of the Concentrations

The ADM building concentrations in 3B and 4B were 180±16 ppb (mean±1.96 standard errors or mean±95% confidence interval) and 232±39 ppb, respectively (Table 3). The difference between the mean concentrations in the two buildings was not statistically significant.

Jacobson *et al*. (1997) reported 80 measurements of H_2S concentration levels from 69 different manure storages using Sensidyne™ colorimetric detector tubes and Jerome™ meter. The concentrations ranged from 6 ppb to 118 ppm. The maximum H_2S concentration in two deep pit pig houses was more than 100 ppm (Jacobson, 1997). It was about 30 times more than the maximum PM concentration and 100 times more than the maximum DM concentration in Table 3.

Table 3. ADM, DM and PM concentrations.

	Building 3B				Building 4B			
	Pit	Chimney	Endwall	Building	Pit	Chimney	Endwall	Building
Days of data	124	124	87	124	95	95	38	95
ADM	154±16	213±18	167±21	180±16	191±36	255±41	378±51	232±39
DM Min	18	14	18	18	24	29	182	28
DM Max	563	590	495	536	1,132	1,082	731	1,107
PM Min	2	3	2	3	1	2	110	1
PM Max	1,098	1,256	1,624	919	2,756	1,824	2,211	1,572

Note: the minimum and maximum concentrations at different sampling locations and in the buildings did not necessarily occur at the same period or in the same day.

Heber *et al*. (1997) reported average H_2S concentrations of 166 ppb in two naturally ventilated swine buildings during cold weather (January to March) using the same model of H_2S analyzer used here. This concentration was close to that measured in 3B. Ni *et al*. (1998) presented partial data from building 3B during warm weather (from June to September). The ADM concentration was 173±21 ppb. The variation of ADM H_2S concentrations in large swine buildings does not seem to be significant.

The variations of H_2S concentrations were evaluated with different time durations and among different sampling locations. The minimum DM concentrations were 14 ppb at the pit chimneys in 3B and 24 ppb in the pit headspace in 4B. The maximum DM concentrations were 590 ppb in the pit chimney in 3B and 1,132 ppb in the pit headspace in 4B.

The minimum PM concentrations were close to zero (0) ppb at single sampling locations for both buildings. However, the minimum PM concentration of 110 ppb at the endwall in 4B was much higher that other locations. The smaller number of measurement days at this location may be the cause of this concentration difference. The maximum PM concentrations were 1,624 ppb at the endwall in 3B and 2,756 ppb in the pit headspace in 4B. The differences between the minimum and maximum PM values in Table 3 compared to the DM data indicated that there were significant diurnal variations of H_2S concentrations.

Avery *et al*. (1975) measured H_2S concentrations that ranged from 120 to 2,174 ppb in six swine units. The sampling time was three hours for each of the 80 samples. The reported concentrations by Avery *et al*. (1975) were within the range of the PM concentrations shown in Table 3.

<u>Seasonal Concentration Variations</u>

Figure 2 (p. 14) presents DM concentrations at three measurement locations in both buildings. There were several days in late June and early July with high mean concentrations. This high concentration group was apparently related to the corresponding low mean airflow rates (Figure 3) and low outdoor temperatures (Figure 4).

The seasonal concentration variation was more evident in 4B, where part of the measurement data in the late June and early July was lost (Figure 2). The seasonal concentration pattern was saddle shaped, with the lowest concentrations during the first half of June and the highest during April and September. This pattern was inversely correlated to the building airflow rate (Figure 3), which corresponded to the seasonal ambient temperatures (Figure 4). The highest DM H_2S concentrations from April 10 to 12 in 4B occurred when the DM building airflow rates were the lowest. The seasonal H_2S concentration variation agrees with Jacobson (1997), who reported peak H_2S concentrations in fall and spring for two deep-pit pig houses.

Except for the last days of the growth cycles, pig numbers decreased slightly while average pig weight increased steadily (Figure 5). The changing pig weight affected the fresh manure production that might influence the gas production inside the pit. However, this effect was not clearly seen in the correlation coefficient analysis (Table 4). Both negative and positive correlation coefficients were obtained between H_2S concentrations and total pig weights. The positive correlation coefficients between H_2S concentrations and pig numbers were largely due to the coincidence of decreasing pig number and increasing ambient temperature during the first cycle.

Table 4. Correlation coefficients between hydrogen sulfide concentrations and other variables.

	Pig size		Temperature		Building airflow	Pit Concen.
	Number	Total W	Outdoor	Room		
Building 3B						
Outdoor temperature	0.31	-0.66	1			
Room temperature	0.36	-0.65	0.92	1		
Building airflow	0.24	-0.38	0.88	0.86	1	
Pit concentration	0.14	-0.20	-0.09	-0.12	-0.37	1
Chimney concentration	0.04	0.08	-0.50	-0.43	-0.69	0.80
Building 4B						
Outdoor temperature	-0.04	-0.27	1			
Room temperature	0.08	-0.47	0.87	1		
Building airflow	-0.14	-0.25	0.87	0.85	1	
Pit concentration	0.38	-0.25	-0.44	-0.19	-0.47	1
Chimney concentration	0.50	-0.40	-0.28	-0.06	-0.40	0.95

Note: Endwall H_2S concentrations are not included, because of small number of available data.

Hydrogen sulfide concentrations were inversely correlated to the building airflow rates, which in turn were directly proportional to the outdoor temperatures (Table 4). The seasonal outdoor temperature variation was an indirect cause of the seasonal H_2S concentration variation. This is especially visible for 4B (Figures 2 to 4). Building ventilation had an effective dilution effect on H_2S concentrations and had a direct impact on the seasonal H_2S concentration variations.

Diurnal Concentration Variations

Four diurnal patterns were identified and evaluated. Patterns 1 to 3 were found in every month of the test (Table 5). Pattern 4 was only found in 4B from April to June. In about 92% of the days (Patterns 1 to 3), the diurnal H_2S concentration variation was correlated to the diurnal ambient temperature fluctuation followed by the building ventilation variation. Higher H_2S concentration occurred almost simultaneously with lower ventilation rate. In the remaining 8% of the days (Pattern 4), gas concentrations were directly proportional to the ventilation rate.

Table 5. Time distribution of four diurnal patterns of hydrogen sulfide concentration.

	March	April	May	June	July	Aug.	Sept.	Total
Building 3B								
Pattern 1	2	0	13	13	14	15	5	62
Pattern 2	2	7	5	6	8	3	7	38
Pattern 3	2	2	3	1	2	10	4	24
Building 4B								
Pattern 1	0	6	11	0	3	6	8	34
Pattern 2	0	3	5	4	3	9	1	25
Pattern 3	0	4	5	3	0	6	2	20
Pattern 4	0	1	4	11	0	0	0	16
Total								
Pattern 1	2	6	24	13	17	21	13	96
Pattern 2	2	10	10	10	11	12	8	63
Pattern 3	2	6	8	4	2	16	6	44
Pattern 4	0	1	4	11	0	0	0	16

Avery *et al*. (1975) found no significant differences between samples taken at different times of the day during a 10-day survey, in which eight samples were taken per day. This conclusion did not agree with our results. Either insufficient number of measurement days or unique ventilation and weather conditions during these days were the reason for undetected diurnal variations by Avery *et al*. (1975).

Pattern 1

This was a typical pattern characterized by quasi-sinusoidal diurnal variation (Figure 6 – 11). It occurred 44% of the time and showed a clear and regular change of H_2S concentration. The highest and lowest concentrations occurred between 3:00 to 6:00 and between 12:00 to 18:00, respectively. The highest APM concentration was 860 ppb at 6:00 at the end wall in 4B (Figure 10) and the lowest was 73 ppb at 12:00 at the end wall in 3B (Figure 11). The greatest APM concentration difference was found at the end wall in 3B for the 16-period measurement (Figure 11), with 360 ppb at 6:00 that was about five times as high as 73 ppb at 12:00.

Pattern 1 variation occurred during fair weather when the outdoor temperature showed a clear sinusoidal fluctuation (Figures 12 and 13). Indoor temperature changed moderately but evidently higher in the afternoon than other times (Figures 14 and 15). The building airflow rate followed the change of temperature with the highest airflow in the afternoon at 12:00 – 18:00 and the lowest in the morning at 3:00 – 6:00 (Figures 16 and 17). The inverse relationship between H_2S concentration and building airflow rate was well established.

Pattern 2

The diurnal variations of H_2S concentration in this pattern were less visible than pattern 1 (Figures 18 – 23). The highest APM concentration was 430 ppb at 6:00 at the end wall in 4B (Figure 22). The ratio of the highest to lowest APM concentrations was always less than 2 for any of the locations.

This concentration pattern occurred during days with outdoor temperature patterns typical of fair weather (Figures 24 and 25). However, there were more variations of outdoor temperatures as compared to Figures 12 and 13 as is evident by the error bars. The APM indoor temperature was a little higher in the afternoon than in the morning and at night (Figures 26 and 27). The building ventilation rate followed the fluctuation of the outdoor temperature (Figures 28 and 29) but there was less difference between the airflow rates in the early morning and in the afternoon. The diurnal building airflow change apparently had less effect on the H_2S concentration variation.

Pattern 3

Concentration variations in this pattern were not characterized by higher values in the afternoon. The APM concentrations of days with 24 periods showed little variations (Figures 30, 32 and 34). More irregularity in concentrations were found in the 16-period days, but the regular diurnal fluctuation of the concentration as in Patterns 1 and 2 was slightly detectable. Pattern 3 occurred during days of cloudy or rainy weather, when the diurnal outdoor and indoor temperature fluctuations were the least (Figures 36 – 39). Although building airflow rates were still visibly higher in the afternoon during these days (Figures 40 and 41), their effect on the H_2S concentrations was not apparent.

Pattern 4

This pattern of H_2S concentration variation was only observed in 4B in April, May and June. It is characterized by a relative higher concentration in the afternoon during 24-period days, or evening during 16-period days (Figures 42 and 43), as compared to lower concentration as appeared in patterns 1 and 2. Pattern 4 occurred on fair weather days for the 24-period data or 16-period days with irregular temperatures (Figure 44). Variations of indoor temperature (Figure 45) and building ventilation (Figure 46) during these days followed that of the outdoor temperature.

The particular characteristic of this pattern is that higher concentrations corresponded to higher ventilation rates. The reason for this correlationship is not known.

Spatial Concentration Variations

The spatial concentration variations between locations in the buildings were evaluated. Results of the spatial H_2S concentration variations are presented in Table 6 as absolute DM concentration differences between any two of the three sampling locations. The minimum and maximum absolute differences in the table were calculated from DM data in the same day. The maximum concentration difference was 271 ppb between the pit headspace and the pit chimneys in 3B. It was 265 ppb between the end wall and the pit headspace in 4B. The DM concentration differences between any of the two sampling locations during the test ranged from 20±6 to 132±17 ppb. These data demonstrate that there existed a significant variation of spatial H_2S concentration in the two buildings under study.

Table 6. Absolute differences of DM concentrations between any two sampling locations.

	DM difference for 3B			DM difference for 4B		
	Pit and chimney	Chimney and end wall	End wall and pit	Pit and chimney	Chimney and end wall	End wall and pit
Min	2	0	0	1	0	52
Max	271	259	181	218	85	265
Mean±2SE	68±9	56±11	41±8	67±13	20±6	132±17
n	124	87	87	95	38	38

The sampling of gas concentrations at three locations (pit headspace, pit chimney and end wall fans) was not done simultaneously. The 10 or 15 minutes of sampling time difference between gas lines did introduce temporal variations in the study of spatial variations. However, when concentrations at one sampling location were continuously lower or higher than another location for more than several hours, then it can be concluded that the spatial concentration difference did exist. The minimum and maximum data listed in Table 6 covered 24 hours of time and the mean data covered the entire test, thus the data proves the existence of spatial H_2S concentration variations.

Airflow in mechanically ventilated animal buildings is highly turbulent. Turbulence is induced by ejecting fresh air into the slow-moving air within the animal building and by shedding behind internal obstructions and solid objects. Pollutant gas generated in manure is transported from the manure pit through the slotted floor area into the occupied airspace of the pig building. The mechanism of this transport is determined by the velocity and the direction of the air mass movement within the building. The velocity vectors depend on the boundary conditions for the inlet and outlet (Krause and Janssen, 1991).

Krause and Janssen (1990; 1991) conducted one-dimensional measurements on the distribution of ammonia (NH_3) in a pig house and found concentration gradients of NH_3 from the floor to the ceiling, with higher concentrations at the floor. They concluded that the greatest gradients were caused by high ventilation rates. De Praetere and van Der Biest (1990) found that the change between high and low ventilation rates affected the airflow patterns in a pig house with fully slatted floor and in the manure pit. Due to the changes of the airflow pattern, important changes in NH_3 concentration at a particular location was observed.

However, reports on the spatial variation of H_2S concentration in swine buildings have not been found. The spatial H_2S concentration variation discussed in this paper suggests the importance of selecting proper measurement locations for specific purposes. For instance, measurement location should be in the animal zone when investigating the animal exposure to H_2S gases. Single spot measurements are not sufficient to represent the mean concentration in a large swine building.

CONCLUSIONS

1) The data in two mechanically ventilated swine buildings during 219 building-days and with 4,544 measurements presented in this paper represent the most comprehensive data set of H_2S concentration in swine buildings ever reported.

2) ADM building H_2S concentrations were 180±16 and 232±39 ppb during the entire test for 3B and 4B, respectively. The building concentration difference did not show statistical significance. The reported ADM concentrations in large swine confinements were close to the results of this study.

3) Seasonal variations of H_2S concentrations existed in the two buildings. DM building concentrations ranged from 18 to 495 ppb in 3B and from 28 to 1,107 ppb in 4B. A saddle-shaped seasonal concentration pattern from April to September was established in 4B. The pattern was not very visible in 3B. However, seasonal weather change and the consequent building airflow change were correlated to the seasonal H_2S concentration variation in both buildings. Higher building airflow rate was the obvious reason for lower DM H_2S concentrations.

4) Diurnal variations of H_2S concentrations also existed in the two buildings. The PM building H_2S concentrations ranged from 3 to 919 ppb for 3B and from 1 to 1,527 ppb for 4B. Four diurnal concentration patterns were identified. In about 92% of the 219 days (Patterns 1 to 3), the H_2S concentrations were inversely correlated to the diurnal building airflow change that followed the outdoor temperature change. The concentration pattern was quasi-sinusoidal with lowest and highest concentrations occurred at 3:00–6:00 and at 12:00–18:00, respectively, during fair weather days. The H_2S concentrations were proportionally correlated to the diurnal building airflow variations during the remaining 8% days.

5) Spatial variations of H_2S concentrations were found between locations which consisted of the pit ventilation chimneys, the end wall fans and the pit headspace. The average DM concentration differences between any of the two sampling locations during the test ranged from 20±6 to 132±17 ppb. The maximum DM difference was 265 ppb between the end wall and the pit headspace in 4B.

6) The significant temporal and spatial variations of H_2S concentrations in the swine buildings demonstrated the importance of choosing proper measurement procedures. To obtain good mean concentration data in large swine buildings, it is necessary to take multi-location measurements and for a sufficiently long time depending on the requirements of the test. The result of a single spot measurement has severe limitations for its validity as a spatial representation.

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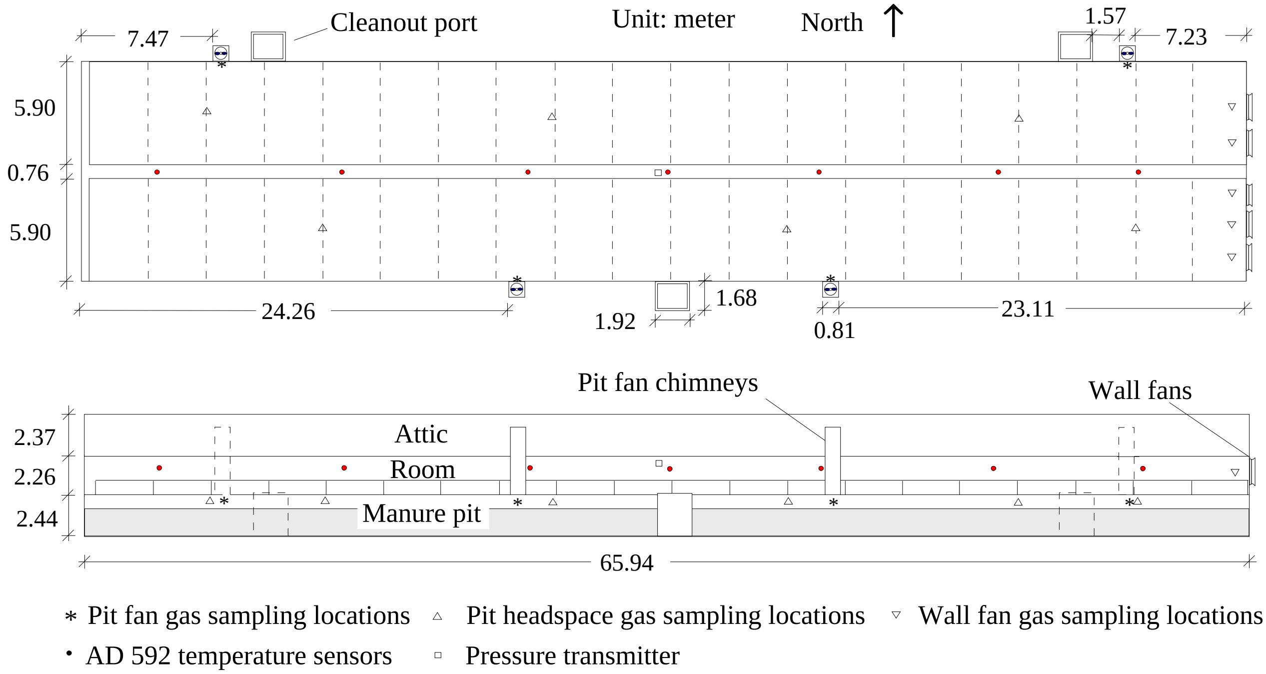

Figure 1. Floor plan (top) and side view (bottom) of the buildings with measurement and sampling locations.

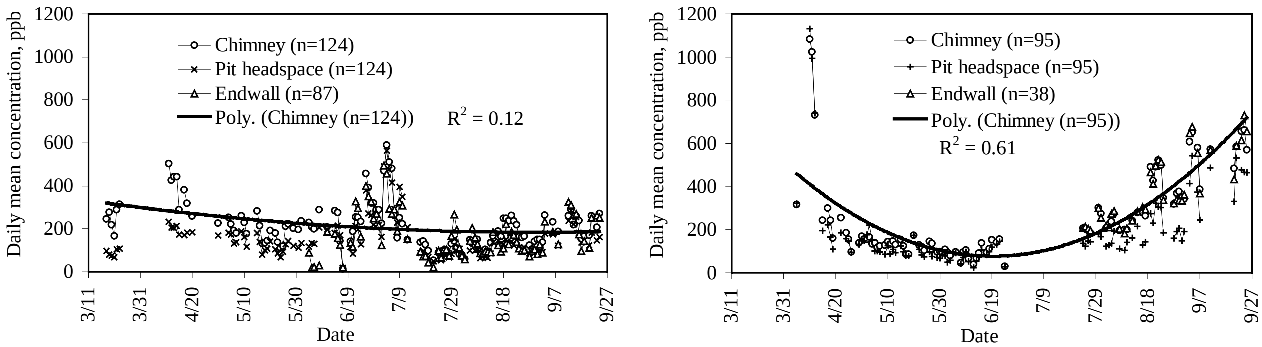

Figure 2. Daily mean concentrations at different locations in 3B (left) and 4B (right).

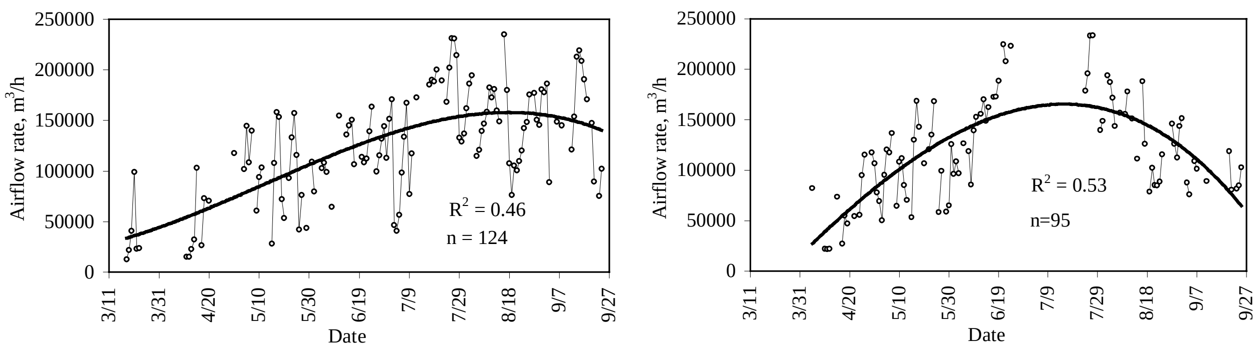

Figure 3. Daily mean building airflow rates in 3B (left) and 4B (right).

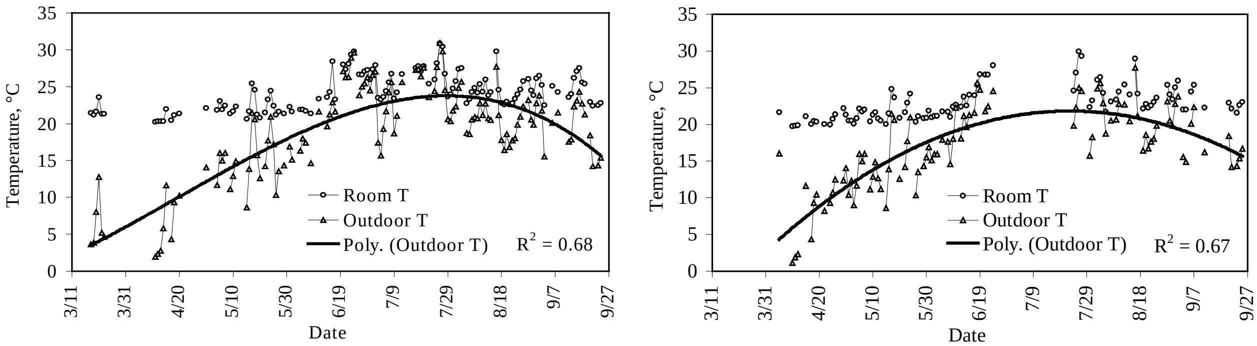

Figure 4. Daily mean indoor and outdoor temperatures for 3B (left) and 4B (right).

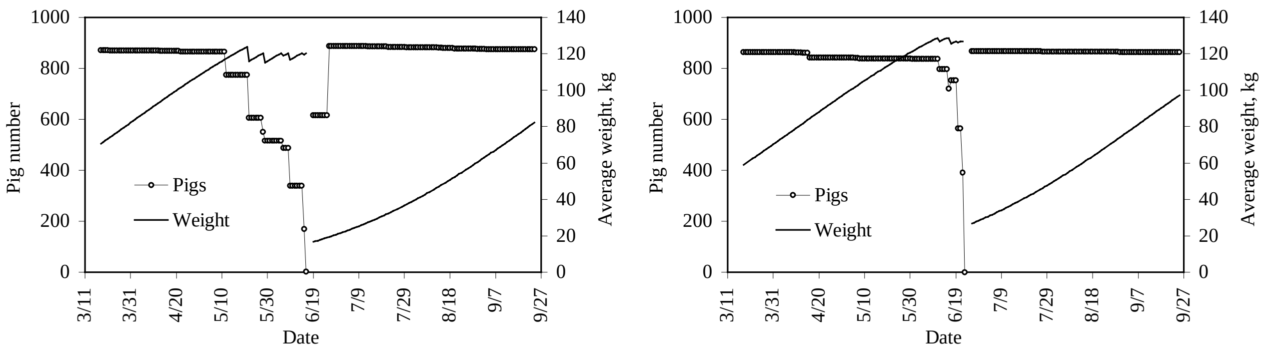

Figure 5. Pig number and average pig weight in 3B (left) and 4B (right).

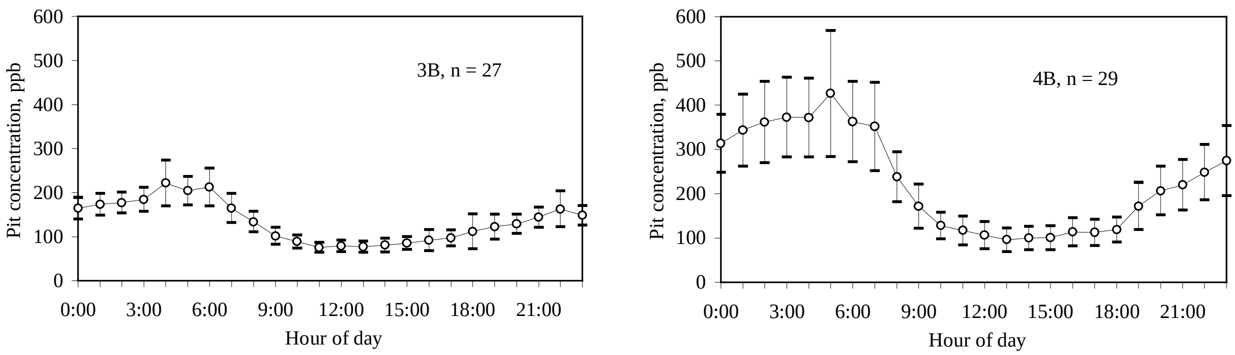

Figure 6. Pattern 1, 24-period variation of pit concentration (mean±2SE) in 3B and 4B.

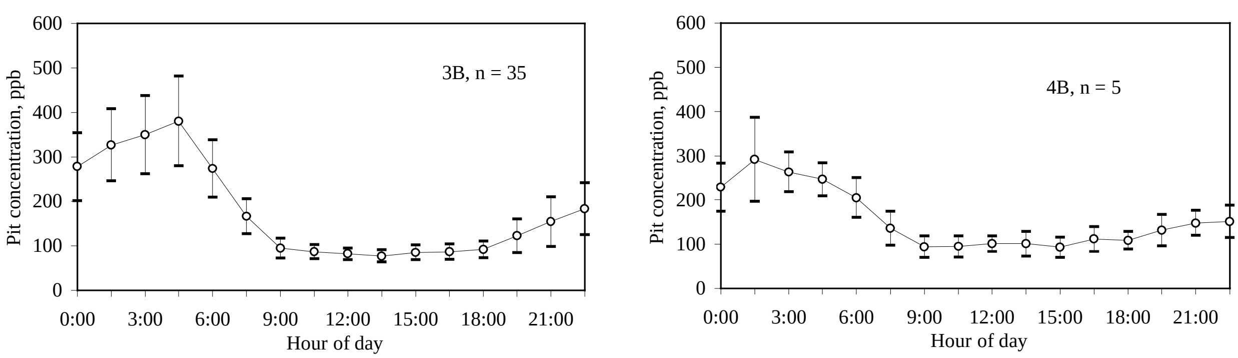

Figure 7. Pattern 1, 16-period variation of pit concentration (mean±2SE) in 3B and 4B.

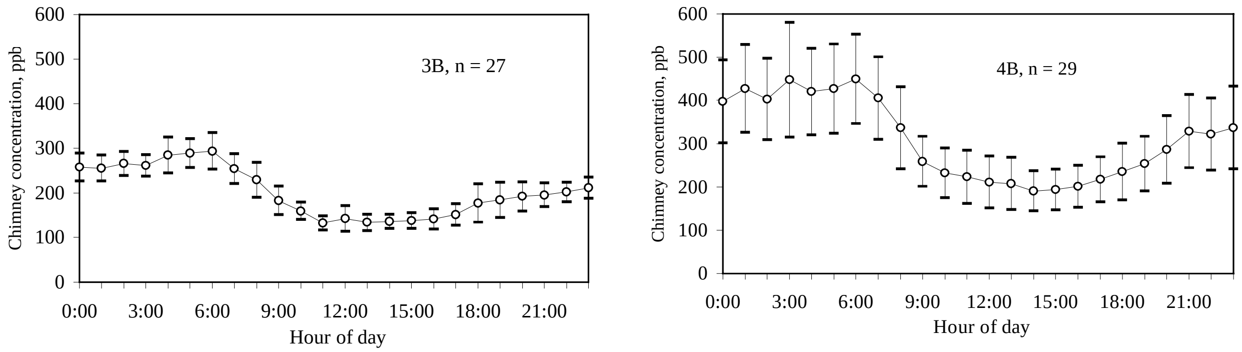

Figure 8. Pattern 1, 24-period of chimney concentration (mean±2SE) in 3B and 4B.

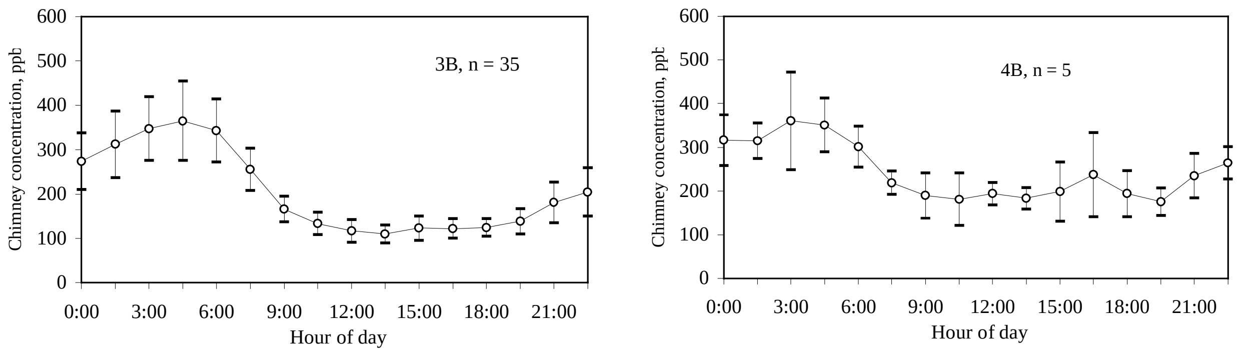

Figure 9. Pattern 1, 16-period of chimney concentration (mean±2SE) in 3B and 4B.

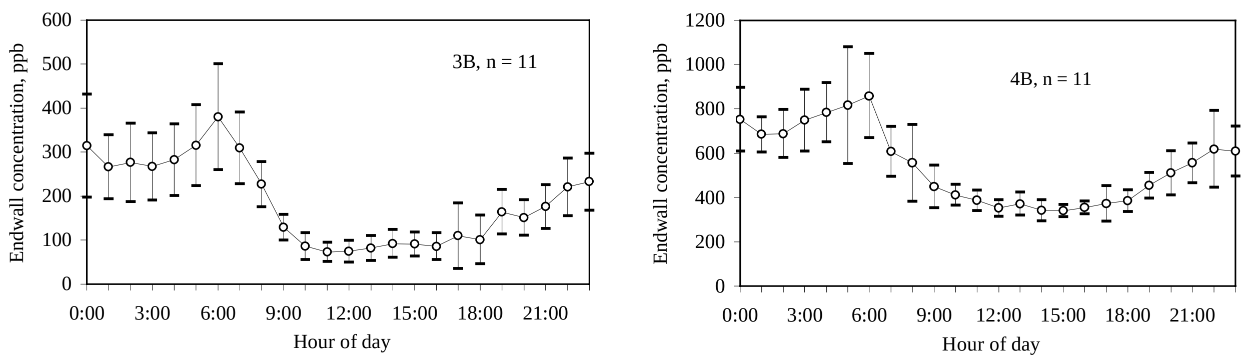

Figure 10. Pattern 1, 24-period of endwall concentration (mean±2SE) in 3B and 4B.

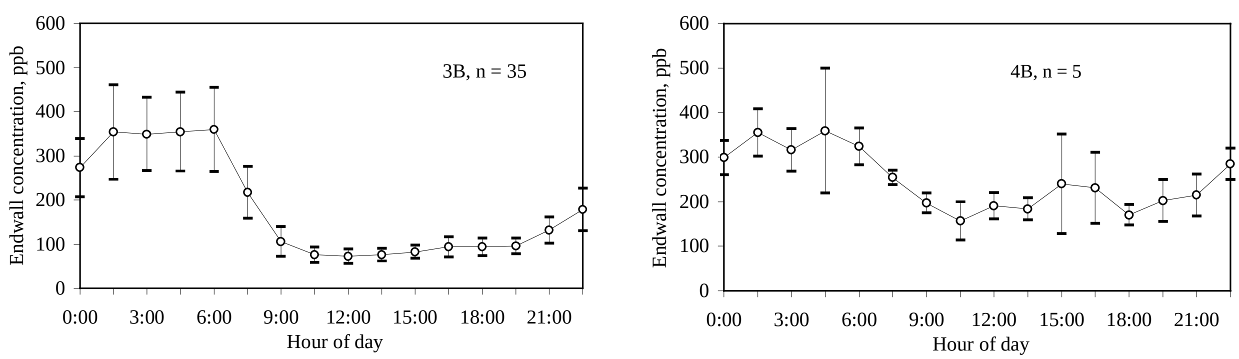

Figure 11. Pattern 1, 16-period of endwall concentration (mean±2SE) in 3B and 4B.

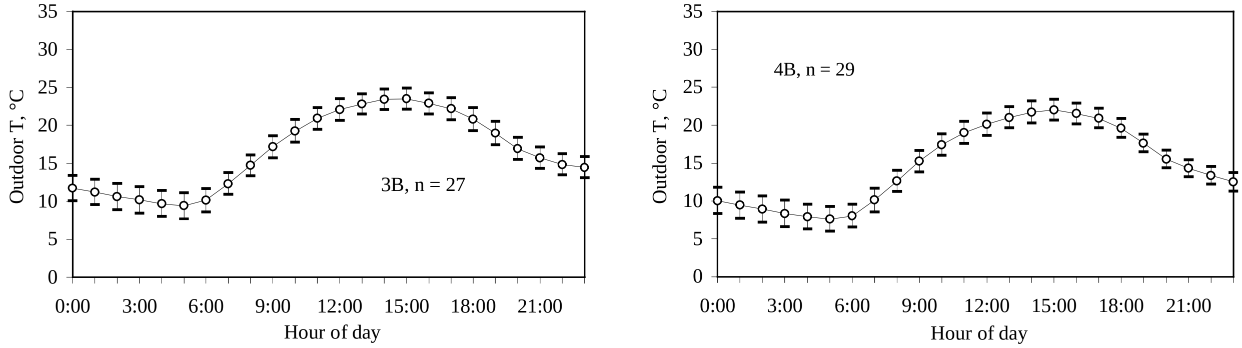

Figure 12. Pattern 1, 24-period variation of outdoor temperature (mean±2SE) for 3B and 4B.

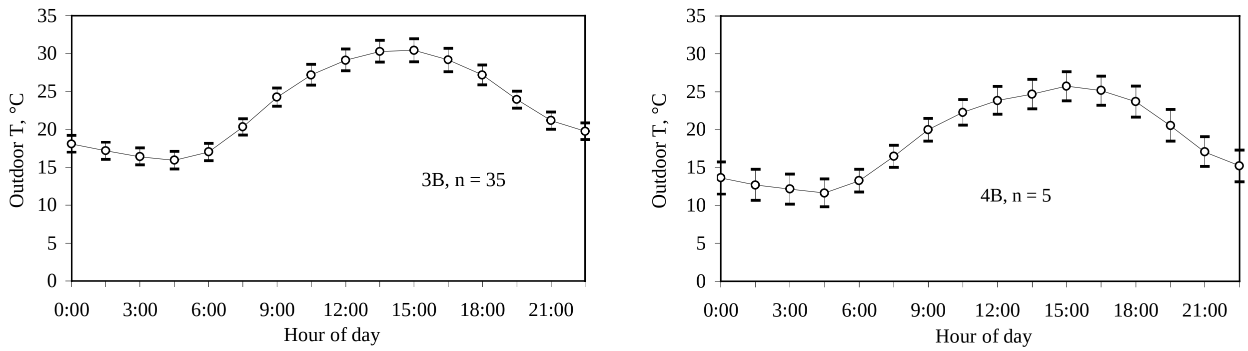

Figure 13. Pattern 1, 16-period variation of outdoor temperature (mean±2SE) for 3B and 4B.

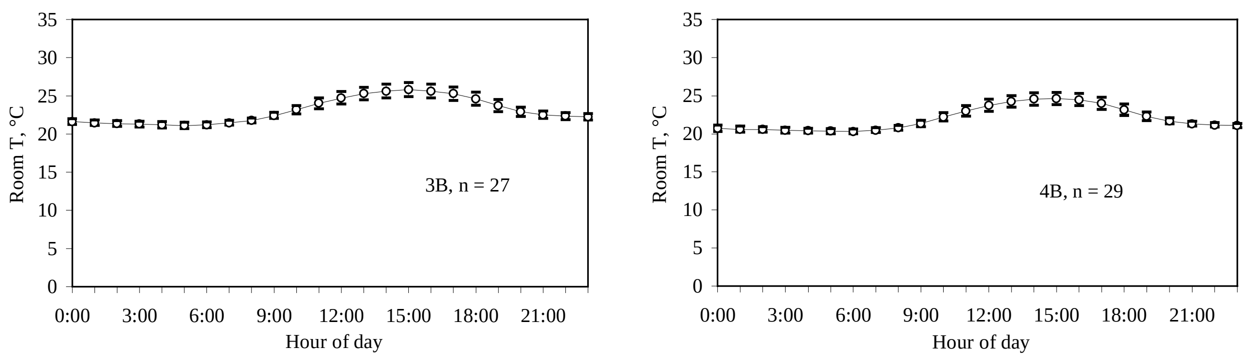

Figure 14. Pattern 1, 24-period variation of pig room temperature (mean±2SE) in 3B and 4B.

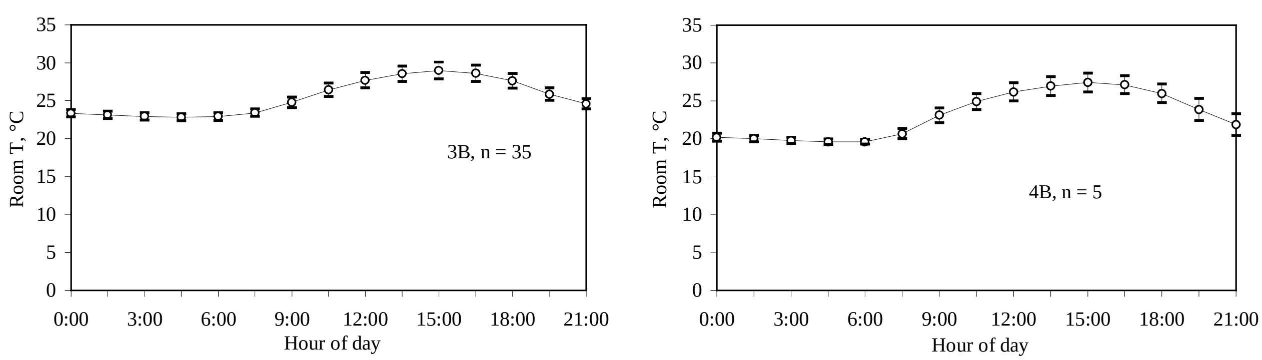

Figure 15. Pattern 1, 16-period variation of pig room temperature (mean±2SE) in 3B and 4B.

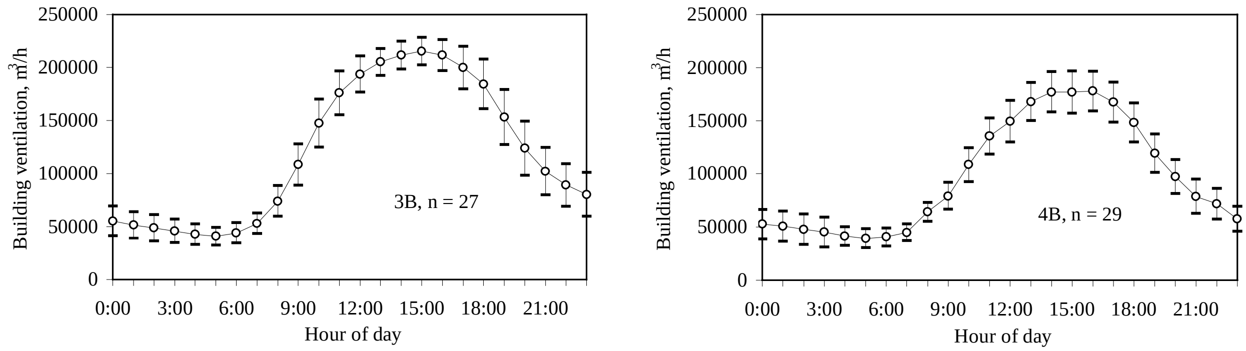

Figure 16. Pattern 1, 24-period variation of building airflow rates (mean±2SE) in 3B and 4B.

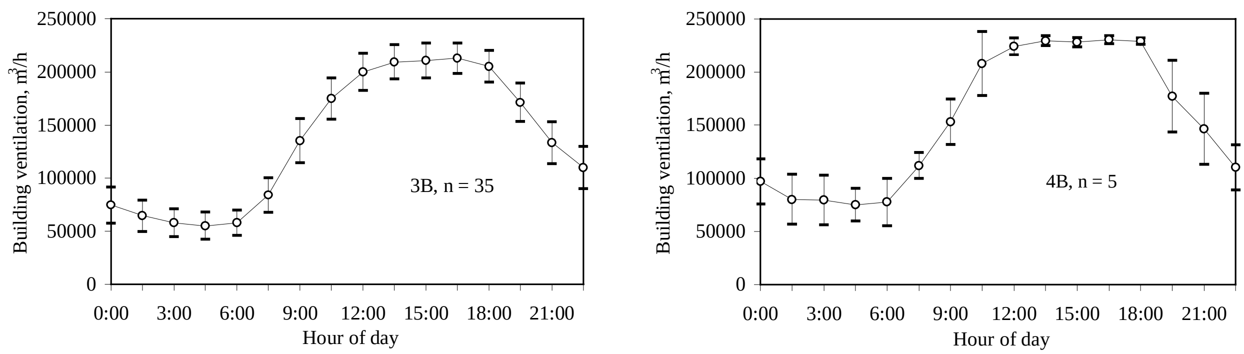

Figure 17. Pattern 1, 16-period variation of building airflow rates (mean±2SE) in 3B and 4B.

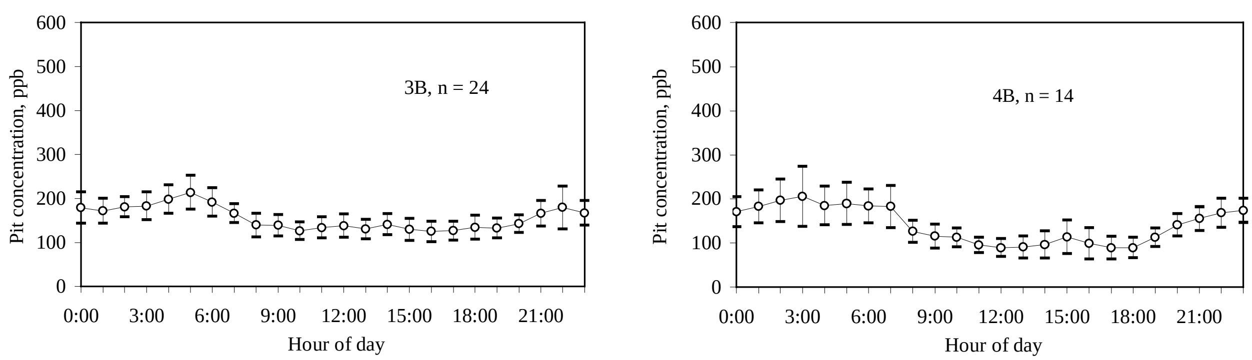

Figure 18. Pattern 2, 24-period variation of pit concentration (mean±2SE) in 3B and 4B.

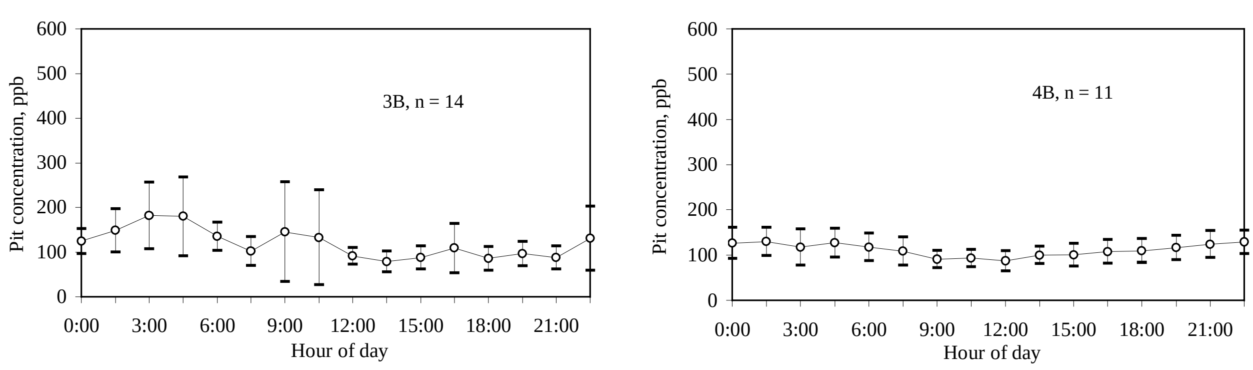

Figure 19. Pattern 2, 16-period variation of pit concentration (mean±2SE) in 3B and 4B.

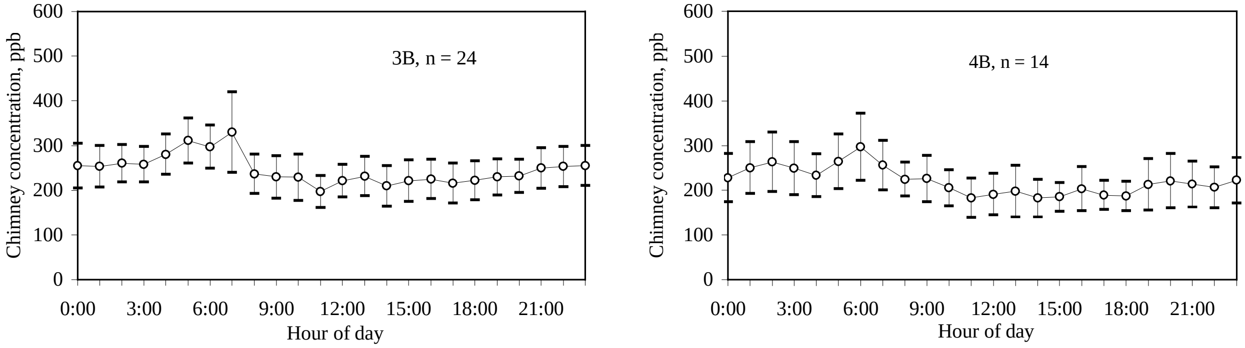

Figure 20. Pattern 2, 24-period variation of chimney concentration (mean±2SE) in 3B and 4B.

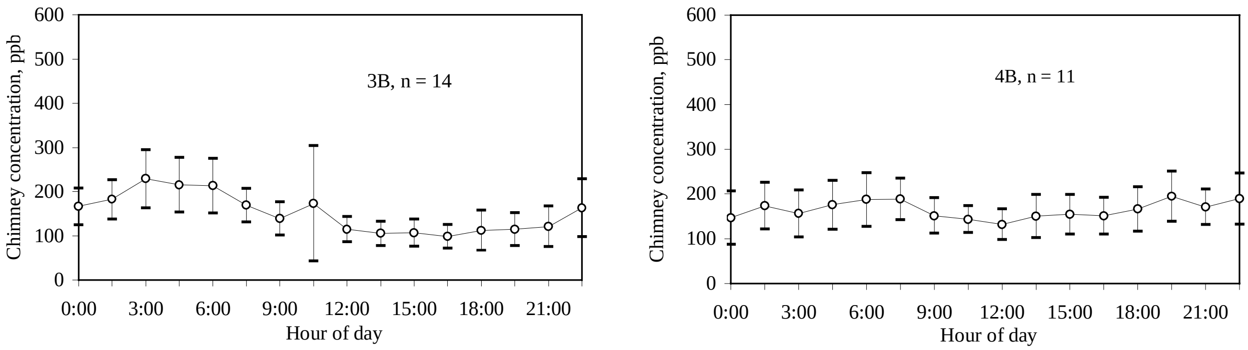

Figure 21. Pattern 2, 16-period variation of chimney concentration (mean±2SE) in 3B and 4B.

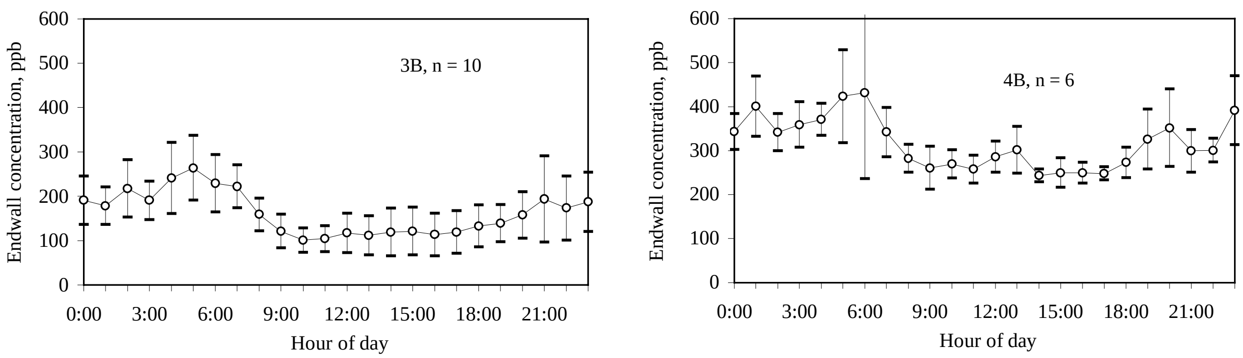

Figure 22. Pattern 2, 24-period variation of end wall concentration (mean±2SE) in 3B and 4B.

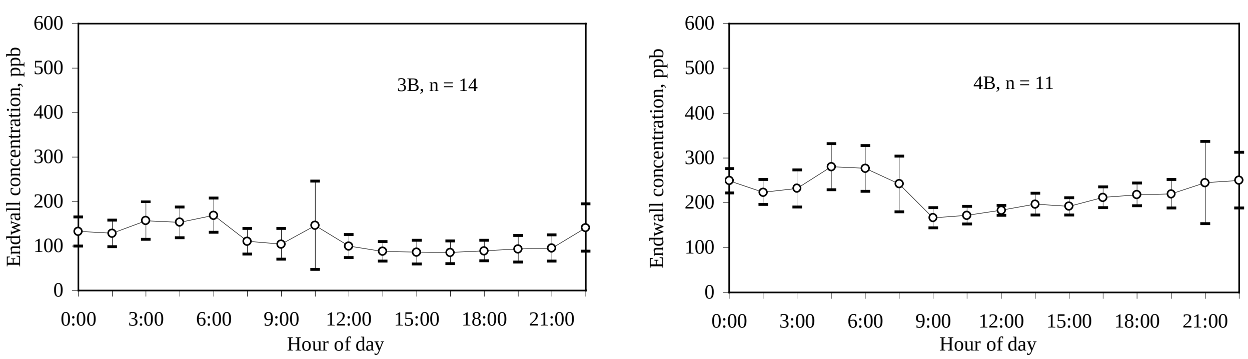

Figure 23. Pattern 2, 16-period variation of end wall concentration (mean±2SE) in 3B and 4B.

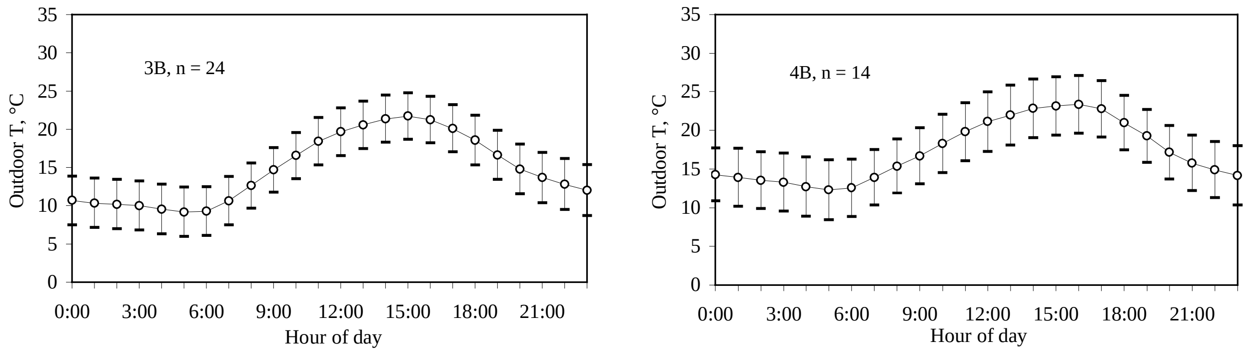

Figure 24. Pattern 2, 24-period variation of outdoor temperature (mean±2SE) for 3B and 4B.

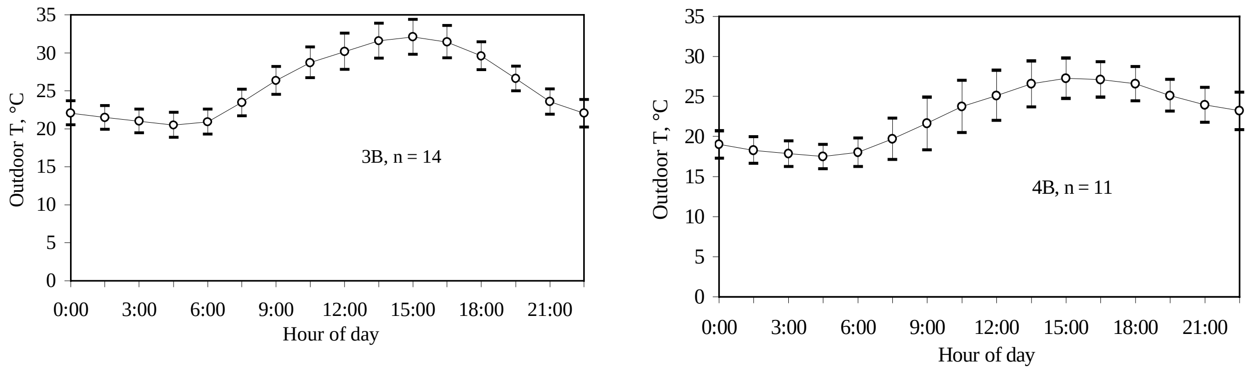

Figure 25. Pattern 2, 16-period variation of outdoor temperature (mean±2SE) for 3B and 4B.

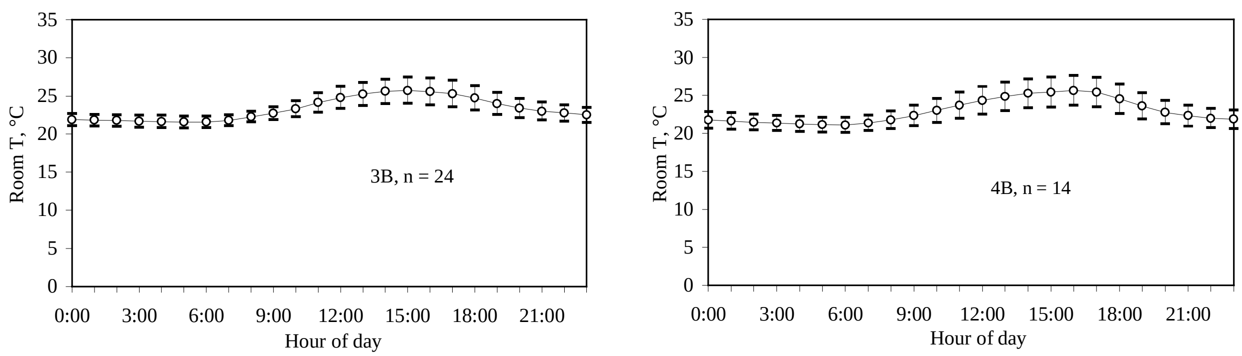

Figure 26. Pattern 2, 24-period variation of pig room temperature (mean±2SE) in 3B and 4B.

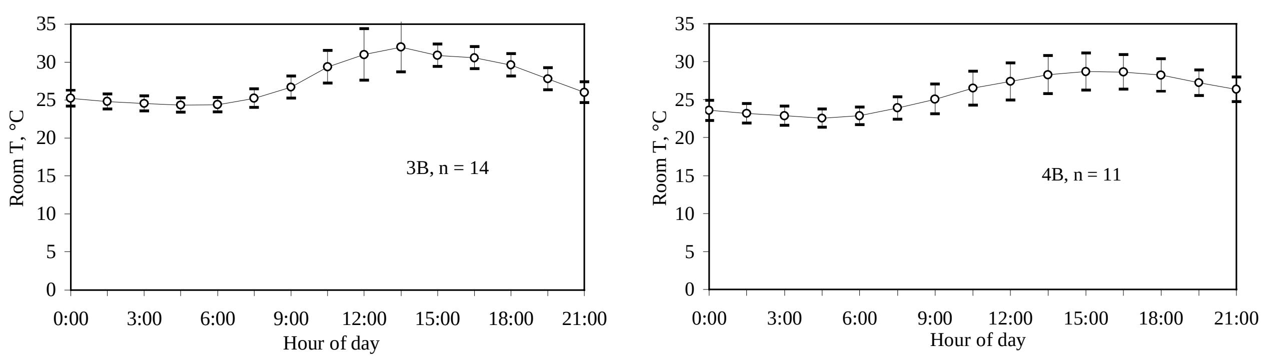

Figure 27. Pattern 2, 16-period variation of pig room temperature (mean±2SE) in 3B and 4B.

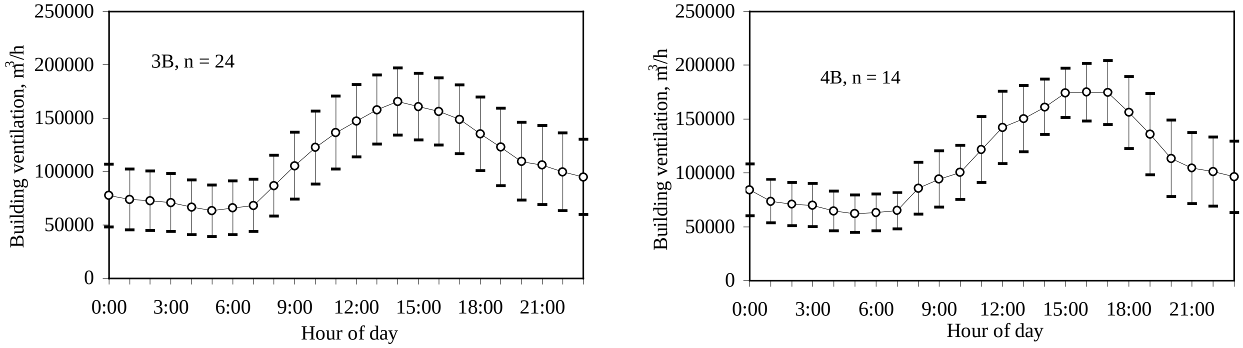

Figure 28. Pattern 2, 24-period variation of building airflow rates (mean±2SE) in 3B and 4B.

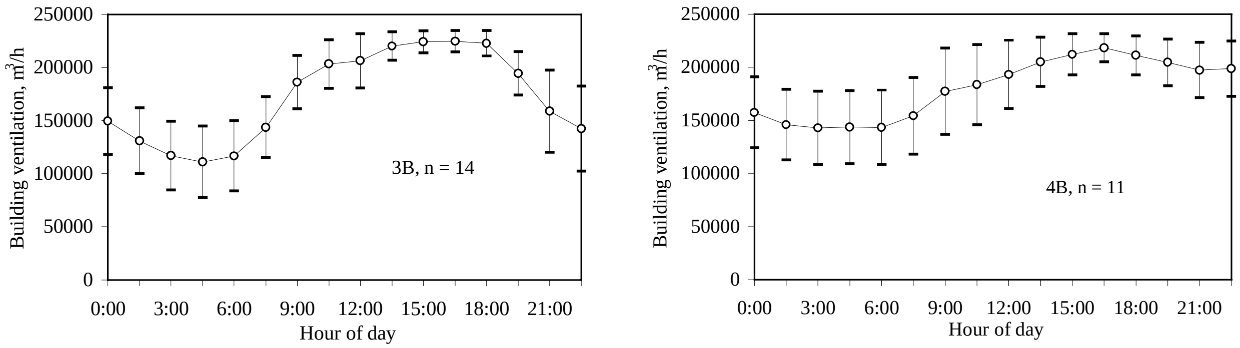

Figure 29. Pattern 2, 16-period variation of building airflow rates (mean±2SE) in 3B and 4B.

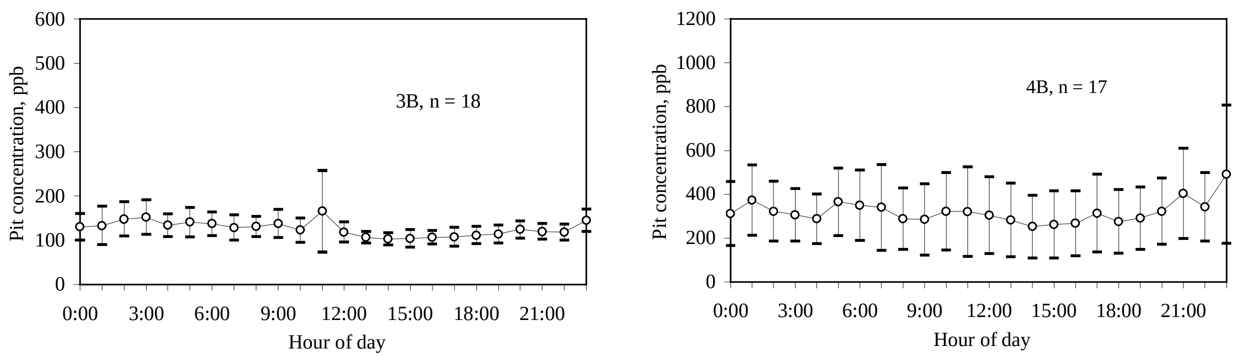

Figure 30. Pattern 3, 24-period variation of pit concentration (mean±2SE) in 3B and 4B.

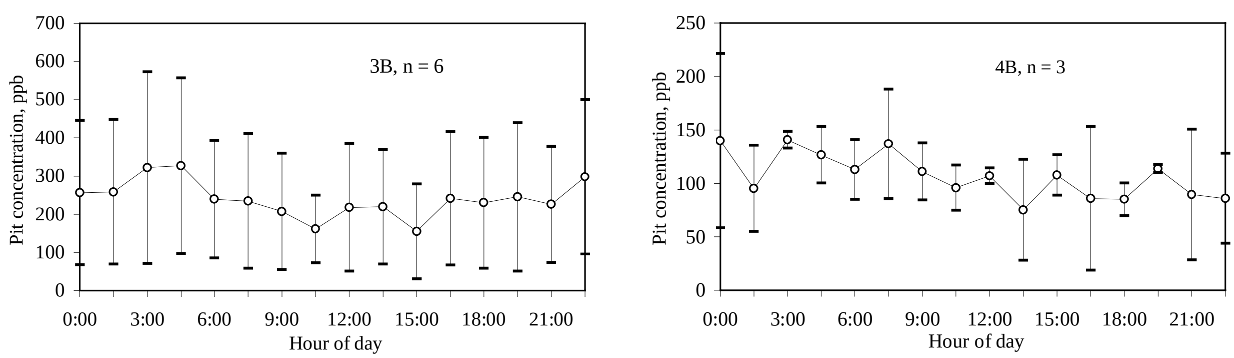

Figure 31. Pattern 3, 16-period variation of pit concentration (mean±2SE) in 3B and 4B.

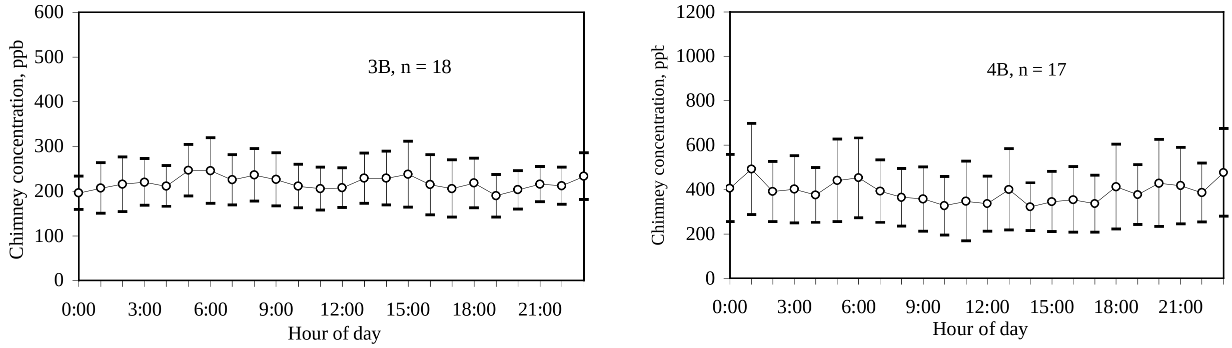

Figure 32. Pattern 3, 24-period variation of chimney concentration (mean±2SE) in 3B and 4B.

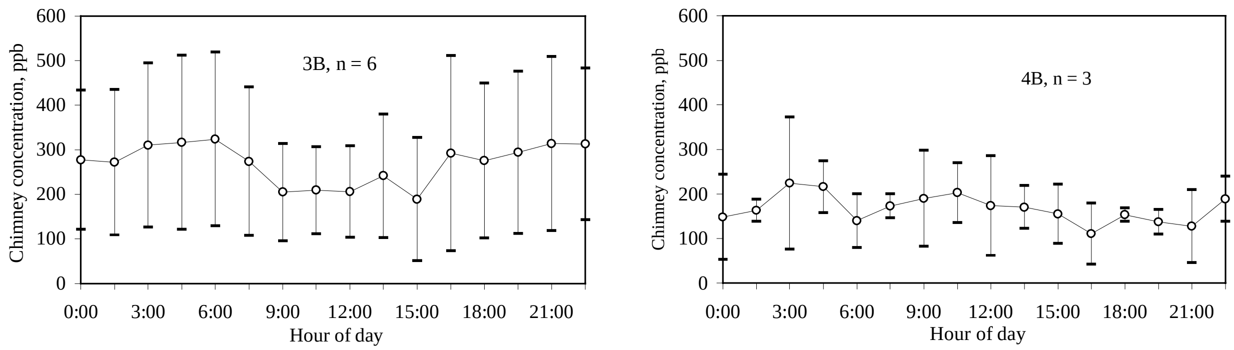

Figure 33. Pattern 3, 16-period variation of chimney concentration (mean±2SE) in 3B and 4B.

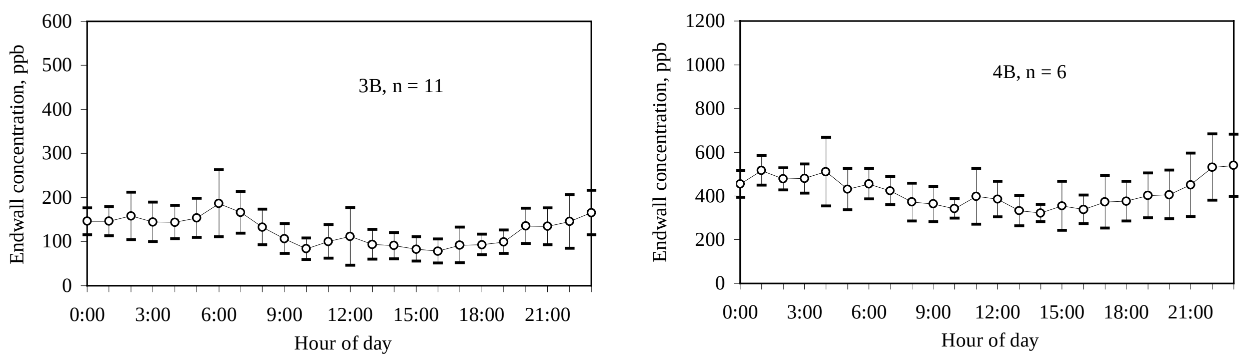

Figure 34. Pattern 3, 24-period variation of end wall concentration (mean±2SE) in 3B and 4B.

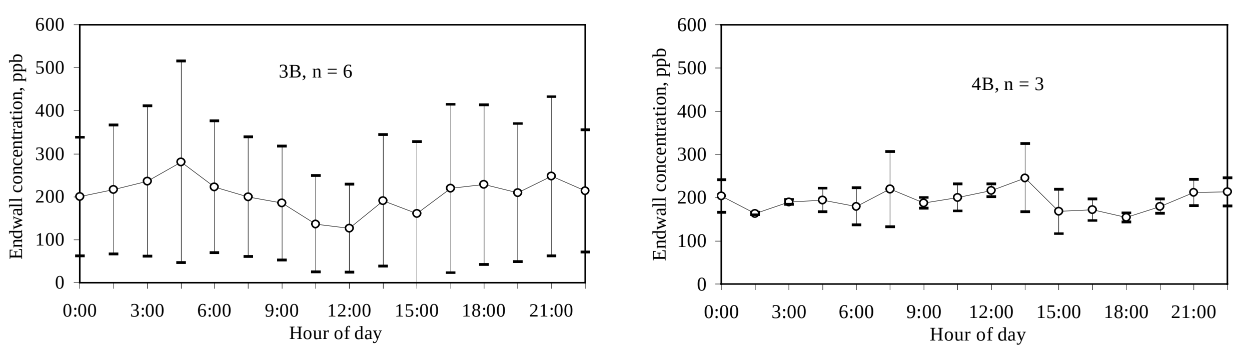

Figure 35. Pattern 3, 16-period variation of end wall concentration (mean±2SE) in 3B and 4B.

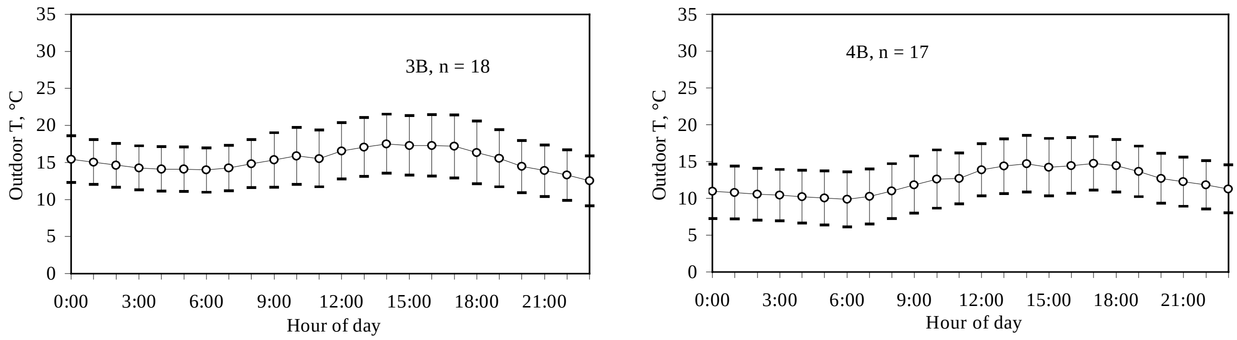

Figure 36. Pattern 3, 24-period variation of outdoor temperature (mean±2SE) for 3B and 4B.

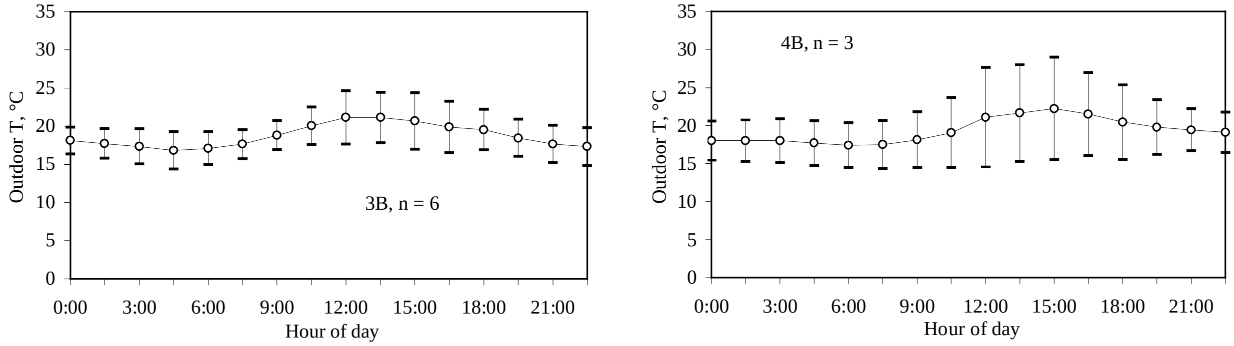

Figure 37. Pattern 3, 16-period variation of outdoor temperature (mean±2SE) for 3B and 4B.

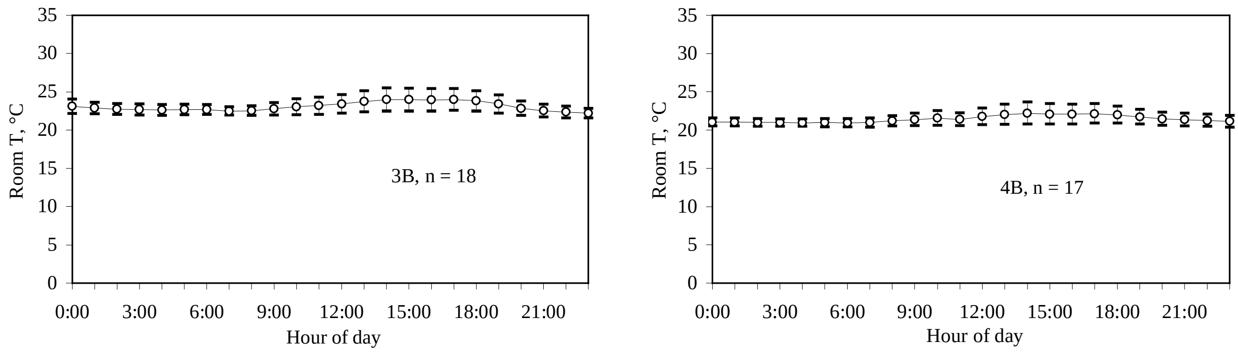

Figure 38. Pattern 3, 24-period variation of pig room temperature (mean±2SE) in 3B and 4B.

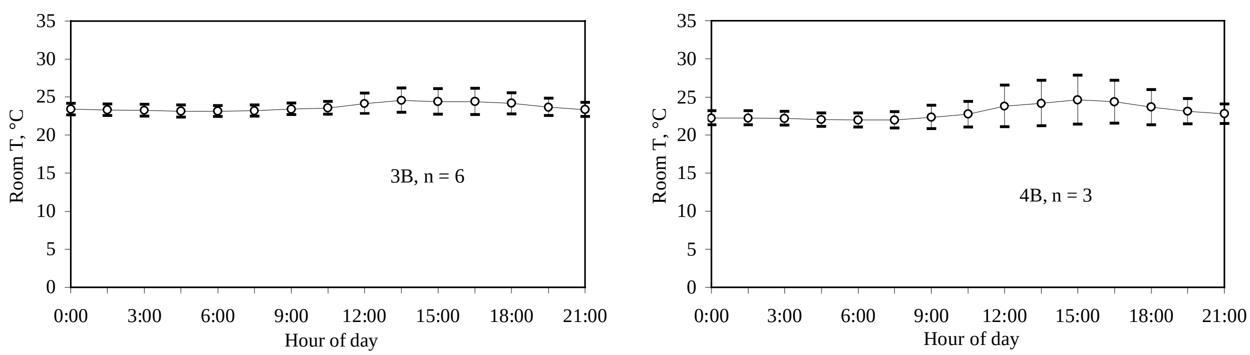

Figure 39. Pattern 3, 16-period variation of pig room temperature (mean±2SE) in 3B and 4B.

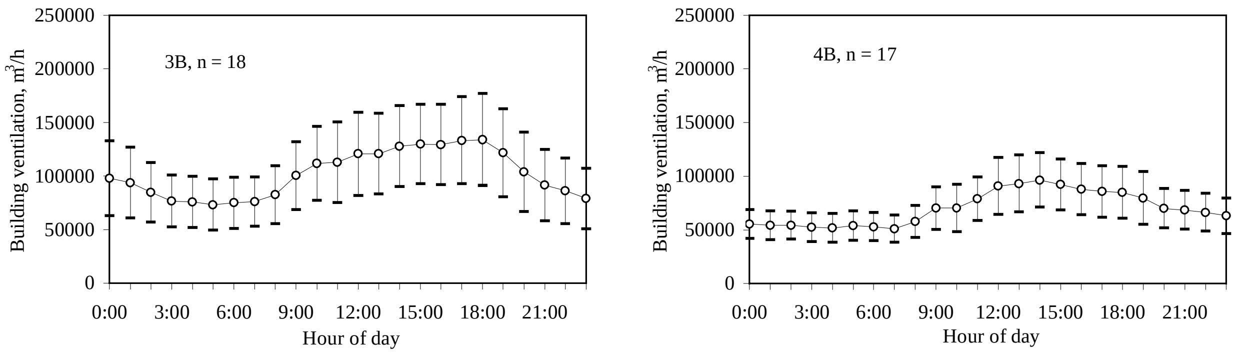

Figure 40. Pattern 3, 24-period variation of building airflow rates (mean±2SE) in 3B and 4B.

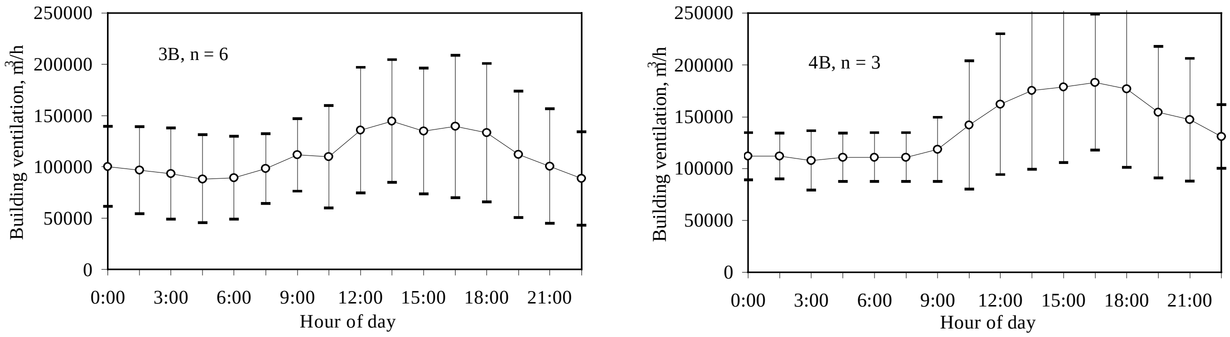

Figure 41. Pattern 3, 16-period variation of building airflow rates (mean±2SE) in 3B and 4B.

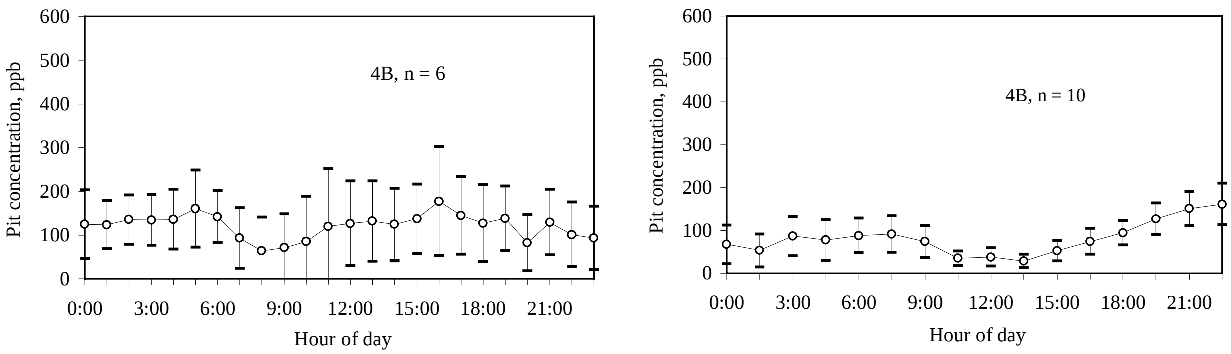

Figure 42. Pattern 4, 24- and 16-period variation of pit concentration in (mean±2SE) 4B.

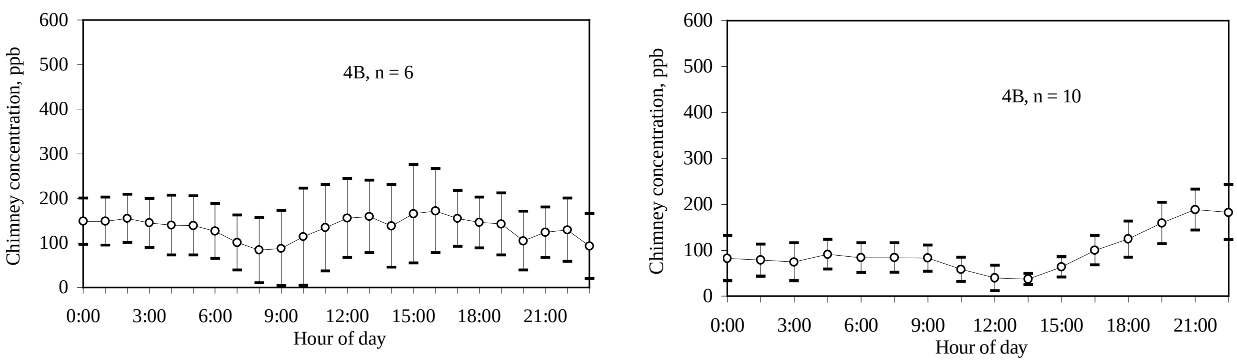

Figure 43. Pattern 4, 24- and 16-period variation of chimney concentration in (mean±2SE) 4B.

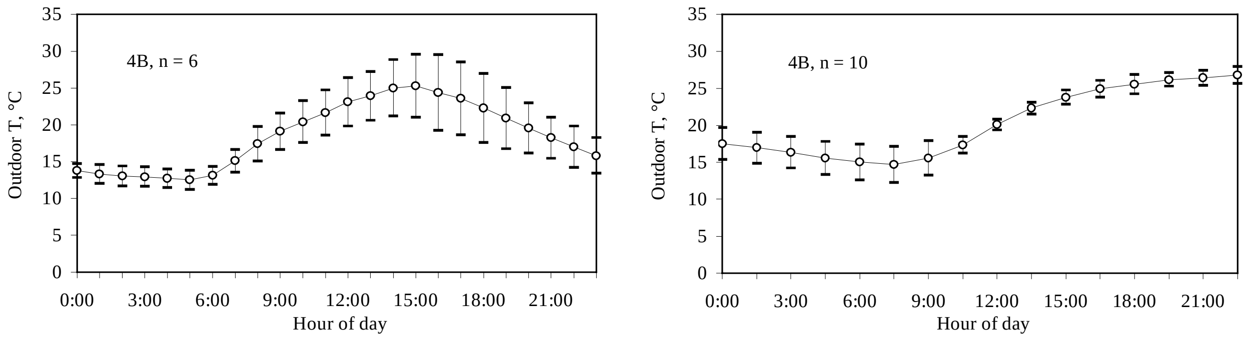

Figure 44. Pattern 4, 24- and 16-period variation of outdoor temperature in (mean±2SE) 4B.

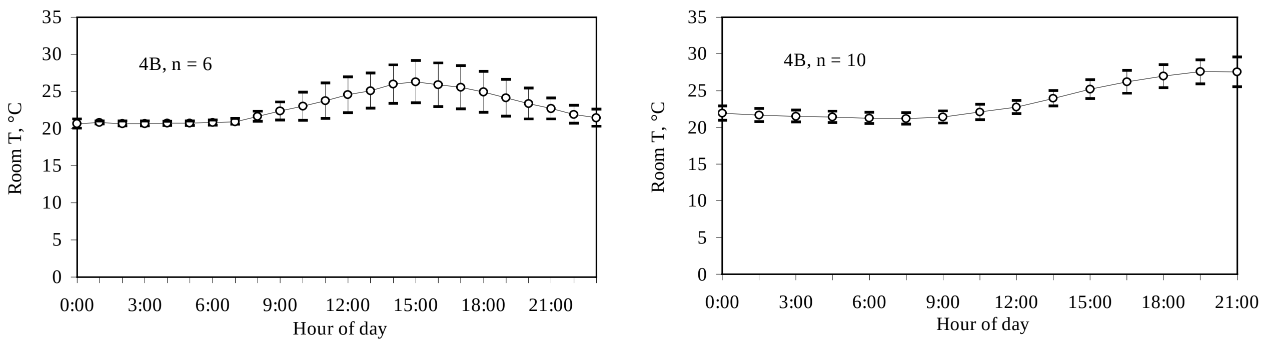

Figure 45. Pattern 4, 24- and 16-period variation of pig room temperature in (mean±2SE) 4B.

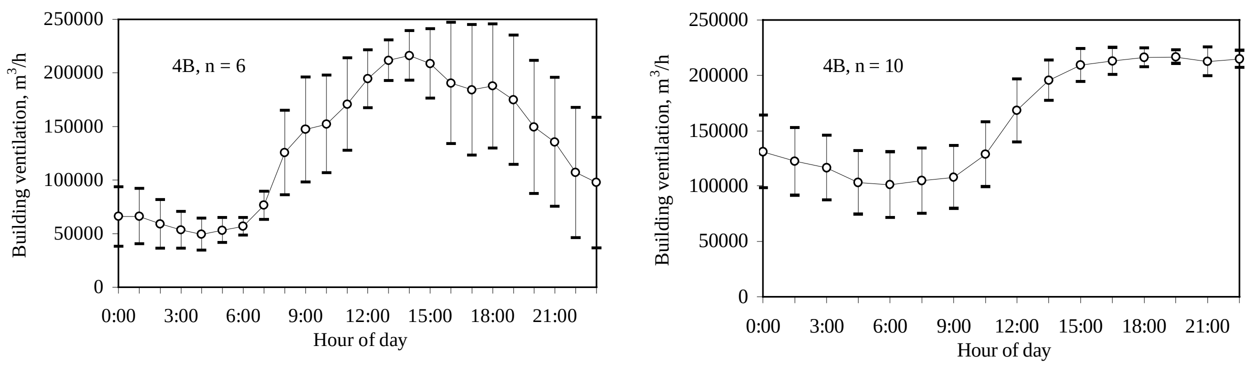

Figure 46. Pattern 4, 24- and 16-period variation of building airflow in (mean±2SE) 4B.