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Is the ammonia concentration highest in the farrowing and piglet-feeding sector on a pig farm?

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Abstract

Introduction and Objective. Ammonia (NH_3) is released during all stages of pig production, with particularly high emissions occurring in the breeding phase. The aim of this study is to compare ammonia concentrations across different sectors of a breed-to-wean pig farm, and to identify their daily variation patterns. Therefore, the exposure of support staff to ammonia in different production sectors may vary. It was assumed that differences in sow feeding strategies – resulting from varying protein and nitrogen levels in rations during mating, gestation, and farrowing/lactation – would lead to differences in ammonia concentrations between production sectors. The initial hypothesis suggested that the farrowing and lactation sector would show the highest ammonia levels.
Materials and Method. The study was conducted from March – October 2023. on a breed-to-wean farm located in the West Pomeranian Province of Poland. Ammonia concentration was measured using a portable multi-gas detector (MultiRAE Lite by Honeywell). Collected data were statistically analysed using the Statistica 13 software package.
Results. Ammonia concentration in pig housing depends on multiple factors, including not only the protein content of the feed, but also ambient temperature and animal density. The study revealed that ammonia distribution across production sectors changed throughout the day, with concentrations peaking in the morning and gradually decreasing afterwards. Statistically significant correlations were found between ammonia concentration in individual sectors and both internal housing temperature, as well as minimum and maximum outdoor temperatures.
Conclusions. Contrary to the hypothesis, the results showed that the highest ammonia levels were recorded in the mating sector rather than in the farrowing and lactation sectors.

Key words
ecological impact, ammonia levels, protein content in diet, feeding strategies in pigs, pig production systems

INTRODUCTION AND OBJECTIVE

Climate change and environmental degradation represent serious global threats. Intensive livestock farming exerts significant pressure on natural resources, posing risks not only to the immediate surroundings of farms but also to all components of the natural environment. This leads to biodiversity loss and contributes to climate change [1]. Livestock farming is responsible for the emission of large quantities of environmentally harmful gases, such as ammonia, hydrogen sulphide, and greenhouse gases, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). In agriculture, synthetic fertilizers contribute to increased greenhouse gas emissions by raising nitrogen levels in the soil, which promotes the release of nitrous oxide [2]. The consequences of increased green-house gas emissions include rising average air temperatures and melting glaciers, which in turn raise sea and ocean levels [3]. In the face of ongoing environmental changes, some animal and plant species will need to adapt to new living conditions, while those unable to do so may ultimately face extinction.

A key characteristic of intensive pig farming is the high concentration of animals in a relatively small area. This creates serious risks not only to the natural environment but also to human health and life [4]. As industrial-scale production increases, so does the risk of air, soil, and water pollution (surface, rainwater, and groundwater). Since the late 20th century, research has been conducted in Europe and globally on the issue of nitrogen pollution from agricultural sources, particularly from livestock production [5]. Ammonia emissions from farms represent a significant environmental problem. It is estimated that livestock production accounts for 75% of agricultural ammonia emissions, with the remaining 25% originating from crop production [6]. The main source of emissions from livestock farms is animal manure, which contains substantial amounts of nitrogen. Pig production is associated with gaseous emissions, including ammonia (NH_3), which occur during housing, manure storage, and the application of natural fertilizers on agricultural land. Ammonia gas, due to dry and acidic deposition, can result in acidification of aquatic and soil environments. Ammonia

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(NH_3) is produced by the decomposition of urea, uric acid, and undigested protein, and has a characteristic irritating odour. It is a colourless, lighter-than-air gas that readily dissolves in water, NH_3 and as an irritant can have serious health effects on humans in the event of excessive exposure [7]. Excessive concentrations of ammonia in livestock buildings have been shown to cause irritation of the conjunctiva of the eyes, damage to the mucous membranes of the respiratory tract, and pulmonary oedema. Long-term inhalation by humans can cause chronic lung disease and liver disease, DNA damage in cells, leading to apoptosis through excessive production of reactive oxygen species. Its impact on the brain is comparable to or greater than acute liver failure, leading to impaired kidney function and Alzheimer's disease [9]. The permissible concentration of ammonia in livestock buildings should not exceed 20 ppm [8].

People directly involved in handling pigs are also exposed to a number of harmful factors, including ammonia.

The European Union (EU) is the world's second-largest producer of pork and the largest exporter of pork and pork products – nearly 4 million tons annually [10], and pig production in those countries is increasing [1]. Among European countries, Poland ranks first in terms of growth in pig production – +9% in 2024 compared to the previous year. In 2019, the European Commission introduced the European Green Deal strategy [11], aimed at combating climate change and protecting the environment. The planned actions focus on the efficient use of resources, preserving biodiversity, and reducing environmental pollution. To protect air quality, EU member states are obligated to reduce ammonia and other atmospheric pollutant emissions. Under these requirements, Poland must reduce ammonia emissions by 1% annually between 2020–2029, and by 17% after 2030, compared to 2005 levels. Each country must develop its own plan of action to achieve the set targets.

In 2020, as part of these obligations, the 'Advisory Code of Good Agricultural Practice for Reducing Ammonia Emissions' was developed [12], which outlines a range of practices contributing to ammonia emission reduction, including various methods and addressing the problem of multiple contributing factors. The methods described therein apply not only to pigs but also to other livestock species, such as horses, cattle, sheep, goats, and poultry. While pigs are the primary source of ammonia emissions, poultry and cattle also contribute significantly. Numerous initiatives address environmental protection, including the Common Agricultural Policy. One area of research that has gained attention is the impact of nutrition on nitrogen content in manure [13].

Due to the environmental nuisance caused by ammonia emissions into the air, as well as the lack of data in this area from pig farms in Poland, it was considered justified to undertake a study aimed at determining the level of ammonia concentration in individual production sectors of a breed-to-wean farm. The study was based on the assumption that, due to differences in sow feeding strategies – resulting from varying levels of protein and nitrogen in the feed rations – during mating, gestation, and farrowing and lactation periods, ammonia concentrations would differ between production sectors. The study hypothesis assumed that the highest ammonia concentration would be found in the farrowing and lactation sector.

Additional aims of the study were to monitor the diurnal variation of ammonia concentration in the different sectors of the piggery and, given existing reports on the influence of temperature on ammonia concentrations, to determine the relationship between ammonia concentration in specific pig housing sectors, and both indoor and outdoor temperatures.

MATERIALS AND METHOD

Description of the piggery and housing system. The study was conducted from March – October 2023 on a breed-to-wean farm with a herd consisting of 5,000 sows, located in the West Pomeranian Province of Poland, The farm produces piglets up to a body weight of approximately 25 kg. All production groups were housed in a slatted-floor, deep-litter-free housing system.

One week before their expected farrowing, sows were moved into farrowing crates equipped with two movable yoke wings. The first separates the sow area from the piglet area, and the second restricts the sows' movement during lactation. The yokes restrict the sows' freedom of movement for five days, including two days before farrowing and three days after farrowing, to minimize the risk of crushing. Piglets stayed in the farrowing crates for approximately 30 days. Manure was collected in the barn's manure channels under the slatted floors, and removed by gravity, by lifting a plug at the bottom of the manure channel. The manure channels were connected to a system of pipelines which transport the manure to a pumping station and then to external earthen tanks. Air intakes to the barn were located in the side walls, just below the roofline. Air was extracted from the barn by fans located in the roof peak. The fans turned on automatically, and the speed regulated by a computer system depending on the internal temperature. The air inlets in the side walls were adjusted in a similar manner. The breeding, low-pregnancy, and gestation buildings each had three fans, each one with a capacity of 15 m^3/h. The farrowing and lactation building has five fans, including two with a capacity of 22.45 m^3/h and three with a capacity of 24.2 m^3/h. The individual production areas where sows were kept were not heated, with the exception of the farrowing and nursing areas. A roofed area for piglet rearing is located in the corners of the farrowing pens. The floor area was equipped with a heating mat.

The content of main macronutrients in the feed rations for different production groups is presented in Table 1.

Table 1. Content of main macronutrients (g/100 g dry matter) in animal diets across experimental groups

Item	Moisture (g/100 g feed)	Crude protein	Crude fat	Crude fibre
Sows during the mating	$11.72^{b*}\pm0.16$	$15.30^{b}\pm0.47$	$3.14^{a}\pm0.23$	$5.20^{a}\pm0.20$
Sows in early gestation	$12.07^{c}\pm0.49$	$14.22^{a}\pm0.60$	$3.26^{b}\pm0.43$	$5.78^{b}\pm0.50$
Sows in farrowing and lactation	$11.15^{a}\pm0.45$	$17.83^{c}\pm1.06$	$4.88^{c}\pm0.32$	$4.06^{c}\pm0.42$

* a, b – mean values in the same column with different superscript letters are significantly different at $p < 0.05$

Ammonia (NH_3) measurement. Ammonia concentration was measured using a portable multi-gas detector (model MultiRAE Lite by Honeywell, RAE Systems, USA). NH_3 concentration was recorded in parts per million (ppm). Measurements were carried out in the sow mating sector

(MS), early gestation sector (GS), and farrowing/lactation sector (FLS). The measurements were taken in triplicate. The total number of measurement days and individual readings is presented in Table 2. Data were collected to cover three successive, maximally populated sow groups. Detailed information on the measurement periods for each sector in all three replicates is provided in Table 3. In each sector, the MultiRAE Lite detector was suspended at a height of 1.5 meters above the floor. This was also to avoid the risk of damage to the device by the animals. NH_3 concentrations were recorded hourly throughout the day. Each day, the device recorded between 8–12 readings between 08:00–18:00. The breeding sector housed approximately 210 sows, which were temporarily housed in individual pens. The gestation sector housed approximately 600 sows. A single room in the farrowing and nursing sector housed 84 sows.

Ammonia concentration measurements were taken in triplicate in all three sectors. In the MS, measurements were taken in March, May, and June, during which period the indoor temperature ranged from 17–21.7 °C. Outside, the lowest temperature during the measurement period ranged from 6–15 °C, and the highest temperature ranged from 15–24 °C. In the GS, measurements were taken from March – June, during which period the recorded indoor temperature ranged from 17–21 °C. The minimum outdoor temperature ranged from 9–14 °C and the maximum outdoor temperature from 17–26 °C. In the FLS, measurements were taken in July, at the turn of August – September, and in October. During this period, the recorded indoor temperature ranged from 23–24 °C. The lowest outside temperature at that time ranged from 7–14˚C, and the highest from 23–25˚C.

Temperatures were recorded using a sensor located in each production sector. Temperature data was transmitted and displayed on the main panel of a computer located in the corridor before the entrance to the pig pen section. The outside temperature was measured using a thermometer hung in a shaded area outside the utility room window.

The shortest measurement duration was in the MS due to post-insemination transfer of sows to the GS, where measurements lasted the longest, targeting the fertilization and embryo implantation period. These data are planned for use in subsequent research.

Statistical analysis. Collected data were statistically analysed using the Statistica 13 software package. Mean values, standard deviations, and minimum and maximum values were determined. The significance of differences between means was assessed using Tukey's and Duncan's tests. Additionally, correlation coefficients between ammonia concentration and indoor and outdoor temperature were calculated.

RESULTS AND DISCUSSION

In all three production sectors, the ammonia concentration (Fig. 1,2,3) was highest in the morning hours, coinciding with the first feeding time, when pigs' physical activity increased after their nighttime rest. Higher NH_3 concentrations – ranging from several to over 30 ppm – were recorded during the months with lower outdoor temperatures. On the other hand, during warmer months, NH_3 concentrations inside the piggery ranged from just a few ppm to slightly above ten.

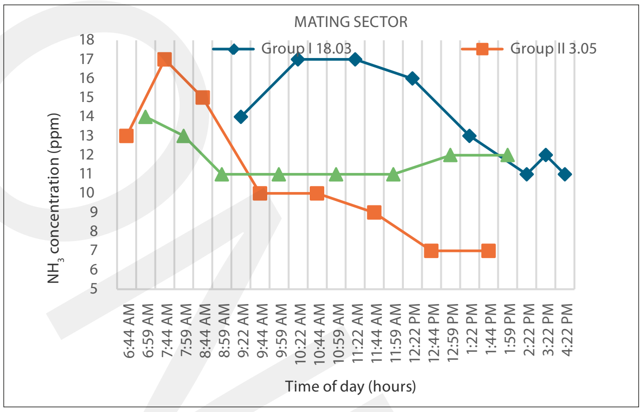

Figure 1. Distribution of ammonia concentration in the mating sector during measurement days

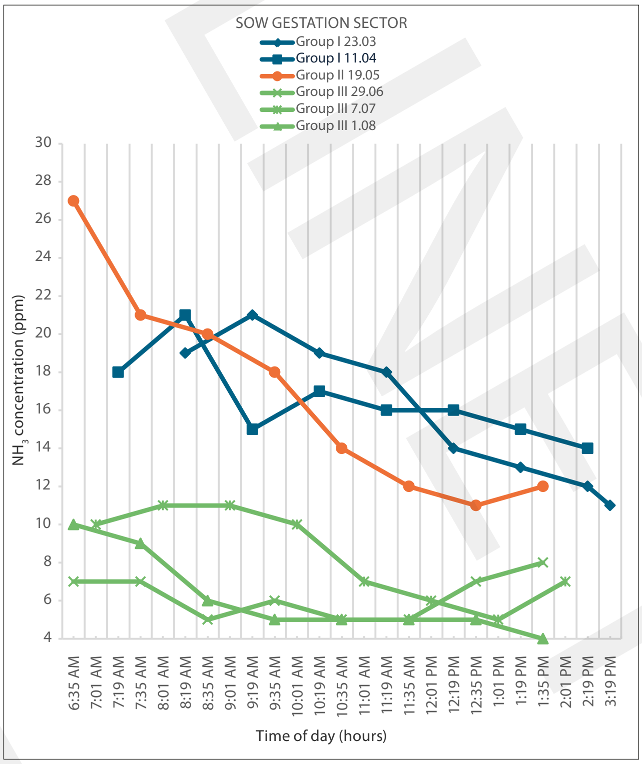

Figure 2. Distribution of ammonia concentration in the gestation sector during measurement days

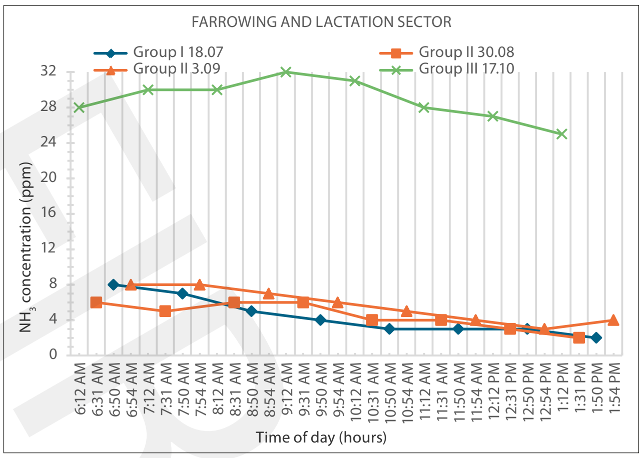

Figure 3. Distribution of ammonia concentration in the farrowing and lactation sector throughout the day

Table 2. Number of measurement days in individual sectors, including groups (measurement replicates)

Sector	No. of measurement days in a sector	No. of easurements in a sector	Average No. of measurements per day
Mating	23	231	10.04
Gestation	55	553	10.05
Farrowing and lactation	39	334	8.56
Group I			
Mating	5	53	10.60
Gestation	25	282	11.30
Farrowing and lactation	18	152	8.44
Group II			
Mating	9	96	10.70
Gestation	15	136	9.10
Farrowing and lactation	11	88	8.00
Group III			
Mating	9	82	9.11
Gestation	15	135	9.00
Farrowing and lactation	10	94	9.40

Table 3. Measurement dates for each sector

Sector	First series of measurements (time period)	Second series of measurements (time period)	Third series of measurements (time period)
Mating	14.03. – 18.03.2023	01.05. – 09.05.2023	27.07. – 04.08.2023
Gestation	19.03. – 13.04.2023	10.05. – 28.05.2023	01.08. – 15.08.2023
Farrowing and lactating	08.07. – 19.07.2023	25.08. – 04.09.2023	14.10. – 23.10.2023

Koerkamp et al. observed comparable values (12.1–18.2 ppm) [14]. This trend may be explained by increased ventilation efficiency in warmer months.

Average NH_3 concentrations per sector (based on three measurement cycles) are shown in Table 2. In the MS for group I, sows (starting 18 March 2023), 53 measurements were taken over five days (10.6 per day, on average). In the GS, 282 measurements were collected over 25 days (11.3/day). The FLS sector was monitored for 18 days, yielding 152 results (8.44/day). For group II, measurements in the MS began on 3 May 2023, and lasted nine days (96 results; 10.7/day). The GS was monitored for 15 days (136 results; 9.1/day), while FLS was monitored for 11 days (88 results; 8.0/day). Group III measurements in the MS began on 27 July and spanned nine days (82 results; 9.11/day). The GS was monitored for 15 days (135 results; 9.0/day), and the FLS for 10 days (94 results; 9.40/day).

The total duration of the study in the MS was 23 days (Tab. 2). During this period, 231 results were obtained, with a daily average of 10.04 measurements. The GS was monitored for a total of 55 days. The total of results from this sector was 553 measurements. The average number of measurements obtained in this sector was similar to the MS – 10.05. In total, measurements from the parturition sector were collected for 39 days, with a total of 334 measurements. The daily average number of measurements from this sector was 8.56.

Table 4 shows ammonia concentrations by sector, with each mean value based on three consecutive measurement periods. The first measurements in the MS began in March, the second in May, and the third in July 2023. The average ammonia concentration in the MS was 11.06 ppm, calculated based on a total of 231 measurements. The minimum concentration in this sector was 3.0 ppm, and the maximum – 24 ppm. A total of 553 measurements were taken in the GS for all three groups. The average ammonia concentration was 13.19 ppm, the minimum concentration – 0 ppm, and the maximum – 38 ppm. In the FLS, the average ammonia concentration was 9.08 ppm, calculated based on 334 measurements. The highest and lowest values were 32 and 0 ppm, respectively. The highest average NH_3 concentration was found in the GS (group II), and the lowest in the FLS (group III). These results did not confirm the initial hypothesis that the highest ammonia levels would occur in the FLS, where sows received the most protein-rich feed (Tab. 1). NH_3 concentration is influenced not only by dietary protein, but also by temperature, animal density, and manure accumulation. Other studies have also failed to confirm that reducing dietary protein effectively decreases greenhouse gases emissions from stored swine manure [15].

Currently, research focuses on more holistic approaches to creating healthy farm environments which helps animal production, including the use of probiotics, prebiotics, and dietary enzyme supplementation [16]. Probiotics have been shown to reduce NH_3 emissions in various swine production groups [17]. Research shows that enzymes help monogastric animals digest organic protein compounds and can also reduce manure odour and NH_3 [18]. Statistically significant differences in average ammonia concentrations between sectors were confirmed ($p < 0.01$), including between the MS (group I) and both the FLS (group III) and GS (group II). This distribution is likely due to higher stocking density in some sectors. Liu et al. [19] reported NH_3 levels in a piggery typically ranged from 0–40 ppm. Ammonia concentrations from pig production vary significantly depending on time of day and season. Reported results regarding seasonal variations in ammonia concentrations have been found to be variable [20].

Interestingly, in a large pig farm in northern China [21], the total carbon footprint of production was 3.39 kg CO_2-eq per kilogram of live weight. Feed production accounted for the largest share of emissions (55%), followed by manure management (28%), energy consumption in livestock

Table 4. Average ammonia concentration (ppm) in individual sectors.

Gas concentration in sectors		Mating sector	Gestation sector	Farrowing/ lactation sector	Significance of differences p < 0.01
		Group I	*Group II*	*Group III*	
NH_3	X	11.06±4.59	13.19±7.77	9.08±8.98	I-II, III II-III
	N	231.00	553.00	334.00	
First repetiton					
NH_3	X	14.34±4.12	17.88±6.80	3.74±3.46	I-II, III II-III
	N	53.00	282.00	152.00	
Second repetition					
NH_3	X	8.25±2.89	11.63±5.21	4.57±2.84	I-II, III II-III
	N	96.00	136.00	88.00	
Third repetition					
NH_3	X	12.24±4.63	4.97±2.74	21.96±5.22	I-II, III II-III
	N	82.00	135.00	94.00	

X – average ammonia concentration; N – total number of measurements in the sector.

buildings (13%), and enteric fermentation (4%). Although emissions related to feed cultivation and transport occurred outside the pig farm itself, they were significantly determined by farm-level decisions, such as the selection of feed source materials and fertilization management. In the context of emissions generated directly on the pig farm, manure management is crucial, with the traditional system based on manure pits and lagoons accounting for a significant portion of the total footprint. The use of more modern solutions, combining manure pits, anaerobic digestion, and lagoons, can reduce greenhouse gas emissions from manure by up to 76%. Electricity consumption for lighting, ventilation, and heating is also a significant source of emissions in livestock buildings, accounting for approximately 13% of the total carbon footprint. The findings of the current study indicate that improving the energy efficiency of pig farms and implementing more advanced manure management technologies are key measures for reducing greenhouse gas emissions within the facility itself. At the same time, significant reduction potential lies in limiting the over-fertilization of feed crops and shortening the transport distances for raw materials, which could reduce the total carbon footprint of production by approximately one-quarter 25%.

Table 4 presents the results comparing the average ammonia concentrations for the first repetition. In the MS, 53 measurements were taken, with an average of 14.34 ppm. In the GS, 282 measurements were taken, with an average of 17.88 ppm. In the FLS, 152 measurements were taken for this group, with an average of 3.74 ppm. The distribution of results from the first series of measurements reflects the distribution of results for the entire study, which included three series of measurements. In the first group, the highest ammonia concentration was also recorded in the GS, and the lowest in the FLS. These differences were statistically confirmed ($p < 0.01$). Significant ($p < 0.01$) lower ammonia concentrations were also observed in the FLS, compared to the MS. Rodríguez et al. [22] found that the average daily NH_3 concentration in piggery with slatted floors ranged from 14.20–16.90 ppm. Similar daily average values of 12.10–18.20 ppm were recorded by Koerkamp et al. [14] in studies conducted in England, The Netherlands, Germany, and Denmark.

Table 4 presents measurements of the ammonia concentration in individual sectors for the second series of measurements. The first measurements were taken in the MS. The average ammonia concentration from 96 measurements was 8.2 ppm. The next measurements were taken in the GS, where 136 measurements were recorded, and the average ammonia concentration was 11.63 ppm. In the FLS, 88 measurements were taken, and the average ammonia concentration was 4.57 ppm. The distribution of results obtained from measurements conducted for the second repetition also reflects that observed for all groups and measurement replicates. Again, the highest ammonia concentrations in the air were found in the GS, and the lowest in the FLS. These differences were statistically significant ($p < 0.01$). This series of measurements also demonstrated statistical significance ($p < 0.01$) in the differences in ammonia concentration between the MS and the GS, FLS. The second highest ammonia concentration was obtained in the MS. The results obtained by Zong et al. [23] showed that NH3 concentrations in summer averaged from 2.10–3.40 ppm, and in winter – 4.20–4.30 ppm.

The ammonia concentrations of the third repetition in each sector are summarized in Table 4. Eighty-two measurements were performed in the first sector, with an average of 12.24 ppm. In the GS, the average ammonia concentration was 4.97 ppm, It was calculated from 135 measurements. In the FLS, 94 measurements were performed, with an average of 21.96 ppm. As can be seen in Table 4, the distribution of ammonia concentration results differed from those in the two previous cases, and the entire analyzed material. In the third repetition, the lowest ammonia concentration was recorded in the GS and the highest in the FLS. The difference between the means for those sectors was statistically confirmed ($p < 0.01$). Furthermore, statistically significant ($p < 0.01$) differences in ammonia concentration were demonstrated between the MS and the GS and FLS. The different distribution of results in this case was likely due to the shorter period of measurements. Banhazi [24] found that higher ammonia concentration values usually occurred in the middle of the night; thus, from midnight – 5:00 AM, values ranged from 3.3–4 ppm. Furthermore, Ni et al. [25] found that higher ammonia concentrations occurred early in the morning, and from 4:00 PM – 8:00 PM. Rodríguez et al. [22] found that ventilation intensity decreased at night, when temperatures were lower, which causes an increase in NH_3 concentration inside the facility.

Table 5 presents the correlation coefficients between ammonia concentration in individual farm sectors and the temperature inside the piggery, as well as the outside minimum and maximum temperatures. The distribution of correlation coefficient values was the same for the first and second replicates, as well as for the entire sample. Only in the third replicate was a positive correlation coefficient value observed. As previously mentioned, the different result could have been caused by a detector failure during the third measurements. Banhazi [24], in turn, stated that ammonia concentrations are not only closely related to ventilation rates, but are more closely related to evaporation rates, which reach a maximum at higher temperatures.

Table 5. Correlation coefficients between ammonia concentration and temperature in the piggery, minimum and maximum outside temperature

Ammonia concentration	Inside temperature	Minimum outside temperature	Maximum outside temperature	Significance of correlation coefficients
A total of three repetitions for all sectors N – 982				
NH_3	-0.3131	-0.5884	-0.6895	**
Firts repetition for all sectors N – 415				
NH_3	-0.6633	-0.7010	-0.8070	**
Second repetition for all sectors N – 320				
NH_3	-0.5561	-0.2986	-0.2761	**
Third repetition for all sectors N – 247				
NH_3	0.6424	-0.7323	-0.6418	**

** $p < 0.01$

CONCLUSIONS

The study showed that the average ammonia concentration in individual sectors did not exceed permissible values, and the distribution of ammonia concentrations in different barn sectors varied throughout the day. Ammonia concentrations were highest in the morning, and then decreased. This pattern may be related to the feeding time of the pigs, whose activity increases after a night's rest. Significant negative correlations were found between ammonia concentration in individual sectors and the internal temperature, as well as the minimum and maximum external temperatures. To explain these results, it can be assumed that as the temperature increased, exhaust fans operated more intensively, resulting in a decrease in ammonia concentration inside the barn. The hypothesis that the highest ammonia concentration occurred in the farrowing and lactation sectors (which could be a result of providing feed with the highest protein and nitrogen content) was not confirmed. The highest ammonia concentration (except for the third measurement cycle) was found in the gestation sector, and the lowest in the farrowing and lactation sector, despite the fact that sows in those sectors were fed feed with the highest protein content. This pattern of results was likely due to the higher concentration of animals in the gestation sector compared to the other sectors, as well as the need to maintain optimal temperatures inside the barn, which required appropriate fan operation.

The ammonia concentration in livestock buildings therefore depends on many factors, including not only the protein content of the animals' feed, but also the ambient temperature, animal density, and the presence of manure in manure channels.

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