

AMMONIA CONCENTRATIONS IN A FREE-STALL DAIRY BARN*

Piotr Herbut, Sabina Angrecka

Department of Rural Building, University of Agriculture in Krakow, al. Mickiewicza 24-28,
30-059 Kraków, Poland

Corresponding author: p.herbut@ur.krakow.pl

Abstract

The paper presents the results of research on indoor ammonia (NH₃) concentrations in the air in a free-stall barn. The differences in measurement results mainly depended on the season and weather conditions. The study also showed a significant correlation ($P < 0.01$) between the NH₃ concentration and temperature, relative humidity and air movement velocity inside the barn. The lowest NH₃ concentration was recorded in the summer (0.0 ppm) in the presence of high air temperatures, low humidity and increased exchange of ventilated air. In winter during severe frosts, highest ammonia concentration (8.0 ppm) was noted, caused by limited ventilation. The highest daily ammonia concentration was usually recorded during the night. This was due to increased relative air humidity and low air velocities. It was concluded that the average level of ammonia of 2.73 ppm during the entire year was significantly below values defined as harmful for animals and people.

Key words: ammonia concentration, indoor air quality, indoor bioenvironment, dairy barn

Ammonia from livestock production is one of the important factors contributing to air pollution (Saha et al., 2010). Ammonia emissions can contribute to the following environmental challenges: acid rains, eutrophication of water (Teye et al., 2008), acidification of soils, or reduced plant biodiversity. The combination of ammonia with other air pollutants may lead to the emergence of respiratory and cardiovascular diseases (Moreira and Satter, 2006). High ammonia concentration in the air causes animal skin irritation and tissue inflammations. Prolonged exposure to ammonia can also decrease cow immunity, increase morbidity and reduce milk production (Osario et al., 2009).

Ammonia in barns is mainly emitted from the following: manure, liquid manure, slurry, litter and feed for cattle (Misselbrook and Powell, 2005; Aguerre et al., 2010). In most European countries, due to the irritating properties of ammonia, the maximum concentration is determined at the level of 25 ppm for an 8-hour working day.

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Sweden being the only exception here, as in this country the maximum concentration is determined at the level of 10 ppm (Groot Koerkamp et al., 1998).

The concentration of ammonia in barns is highly variable and depends on the type of building, its volume, ventilation system, livestock density, barn management system, and the frequency of cattle manure removal. Other significant factors also include: air temperature, air humidity, air velocity, and air change rates which are basic factors influencing microclimate inside livestock buildings, in particular barns (Wathes et al., 1998; Nawalany, 2012; Herbut et al., 2012).

Highly productive cows need plenty of fresh air with suitable quality, because insufficient amounts of oxygen slow down their metabolism, which in turn affects milk production. Insufficient ventilation air exchange inside the barn causes increased air humidity as well as concentration of noxious gases produced as a result of animal waste decomposition. High air humidity may have a negative impact on animal welfare and lead to bacteria development (Albright and Timmons, 1984; Zähler et al., 2004; Herbut et al., 2013).

Therefore, the aim of this study was to determine the impact of changing weather conditions during the year on ammonia concentration levels in a free-stall barn. The temperature and humidity as well as air movement in correlation to the concentration of ammonia were analysed. Based on this research, it was possible to determine annual concentration of ammonia, and the reasons for its changeability.

Material and methods

The research was conducted in a free-stall barn that houses 176 dairy cows of the Holstein Friesian breed in the period of September 2011 to December 2012.

The usable floor area of the building was 1580 m². The building was located in the village of Kobylany, the Małopolska Province (N: 50° 8' 59" E: 19° 45' 12"). It was oriented along the east-west axis. It was a typical building constructed from pre-fabricated reinforced concrete with a double-pitched roof (gradient 45%). The building was equipped with a natural gravitational ventilation system in longitudinal walls and outlet openings in the form of ridge vents. Technical parameters of the researched barn are presented in Table 1.

Table 1. Technical parameters of the dairy barn in Kobylany

Parameters of the barn	Unit	Value
Usable floor area	m ²	1580
Population	cow	176
Usable floor area per animal	m ² ·cow ⁻¹	9
Usable cubage per animal	m ³ ·cow ⁻¹	53
Total area of outside walls	m ²	992
Curtains area	m ²	207
Door area	m ²	54

Manure was removed mechanically from manure corridors twice a day directly to the manure pad located on the west side of the building. The boxes were laid with straw once a day. The cattle were fed according to the total mixed ratio method twice a day.

During the research in the barn were located a few ammonia sensors at the level of 1.0 metre above the floor in selected areas of the barn. The sensors measured temperature and relative humidity as well as air velocity and ammonia concentration.

Comparison of the results obtained and the measurements of momentary ammonia concentration indicated that the values from the measurement point located in the central part of the barn was the most representative of the whole area of the barn. The variability of outside weather conditions, such as temperature, relative air humidity, air speed and direction, was recorded with the help of a meteorological station located on the west side of the barn (Figure 1).

All measurements were conducted at 6-minute intervals and recorded automatically.

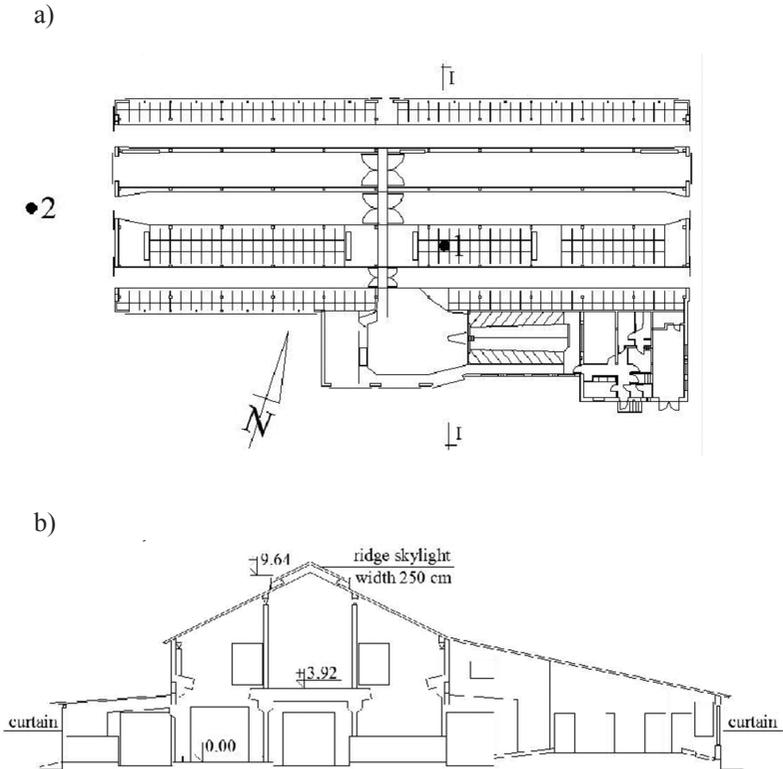


Figure 1. Location of measurement points:

1 – inside the barn; 2 – meteorological mast; a – projection, b – cross-section I-I

Table 2. Average values (minimum – maximum) of the measured air parameters for selected periods of research

Research period	Winter		Spring		Summer		Autumn	
	30.01–6.02.2012	19–26.02.2012	18–24.04.2012	19–31.05.2012	5–11.07.2012	18–24.08.2012	24–30.09.2012	18–26.11.2012
Ti	-9.8 (-16.1–-3.9)	5.0 (-1.6–9.2)	11.8 (6.6–20.0)	19.0 (9.1–28.8)	24.8 (18.2–35.1)	24.2 (15.5–33.1)	17.2 (10.7–25.1)	8.3 (2.0–12.0)
Te	-15.6 (-21.7–-9.4)	1.7 (-6.0–6.3)	8.2 (2.2–17.9)	17.4 (6.0–27.5)	23.3 (15.6–33.4)	22.9 (12.6–33.2)	15.5 (7.0–25.1)	4.8 (-1.6–9.1)
RHi	69.4 (56.5–77.8)	74.7 (53.3–90.9)	65.4 (40.9–84.4)	57.3 (33.6–87.1)	64.6 (36.4–89.7)	60.7 (29.8–89.1)	70.3 (44.8–90.5)	85.5 (74.3–91.0)
RHe	69.7 (55.4–78.5)	79.2 (47.0–95.7)	70.5 (36.6–94.9)	59.3 (31.3–95.6)	66.8 (34.2–96.4)	62.9 (28.7–96.2)	74.2 (43.7–95.9)	94.4 (80.2–96.6)
Vi	0.6 (0.3–1.1)	0.4 (0.1–1.5)	0.3 (0.1–0.6)	0.5 (0.1–1.4)	0.4 (0.1–1.4)	0.5 (0.1–1.4)	0.5 (0.2–1.7)	0.3 (0.0–1.0)
Ve	1.7 (0.0–4.6)	3.5 (0.0–10.2)	1.9 (0.0–4.6)	1.8 (0.0–4.7)	1.2 (0.0–3.4)	1.3 (0.0–4.8)	1.6 (0.0–6.5)	0.8 (0.0–3.8)

Ti – inside air temperature (°C).

Te – outside air temperature (°C).

RHi – relative inside air humidity (%).

RHe – relative external air humidity (%).

Vi – indoor air speed (m·s⁻¹).Ve – wind speed (m·s⁻¹).

Air movement velocity was measured with the help of HD 103T sensors, produced by Delta Ohm. Their measurement range was $0\text{--}5\text{ m}\cdot\text{s}^{-1}$, with the measurement accuracy of $0.04\text{ m}\cdot\text{s}^{-1}$ in the range of $0\text{--}0.99\text{ m}\cdot\text{s}^{-1}$ and measurement accuracy of $0.02\text{ m}\cdot\text{s}^{-1}$ in the measurement range of $1\text{--}5\text{ m}\cdot\text{s}^{-1}$. Temperature and relative air humidity were measured with the help of integrated sensors LB-710 produced by Label (measurement range: -40 to $+85^\circ\text{C}$; humidity: 0 to 99.9% ; measurement accuracy: 0.1°C and 0.1%). The concentration of ammonia was registered with the help of gas detector Unitox IV produced by Pro-service in the measurement range of $0\text{--}100$ ppm and measurement accuracy 0.5 ppm.

The data were statistically analysed with Statistica version 10.0 (StatSoft) software. The Pearson correlation coefficients (r) between ammonia concentration and relative humidity, air temperature, air velocity inside and outside the barn were calculated. The t-Student test was used to estimate the statistical significance of the values obtained. Data are considered significant if $P < 0.01$.

Results

Based on the two-year results of research, the authors selected most representative periods for the needs of statistical analysis. These periods were characteristic for their concentration of ammonia in seasons of the year (Table 2).

For the purposes of this publication, only selected periods for each time of the year have been presented in the charts. The remaining charts and results are in the possession of the authors.

Winter

In the period of 30 January to 6 February 2012, during severe frosts, when the ventilation inside the barn was significantly reduced by closing the door and raising the curtains on longitudinal walls, the difference between T_i and T_e was -6°C . Relative humidity fluctuations were similar, whilst RH_i showed higher values (Figure 2 a, b).

This period was distinctive for high wind speeds, which despite raised curtains, caused increased air speed inside the barn, far exceeding the recommended value for cattle in winter: $0.2\text{ m}\cdot\text{s}^{-1}$ (Figure 2 c).

In this period of the year, the concentration of ammonia ranged between 5.5 and 8.0 ppm. The fluctuations between $11:00$ and $15:00$, visible in the chart, were the result of open doors of manure corridors during the removal of manure. The fact that these doors were opened on a regular basis also contributed to the highest daily decrease of relative humidity. Another consequence of that was increased air velocity and increased exchange of ventilated air, which reduced the concentration of ammonia.

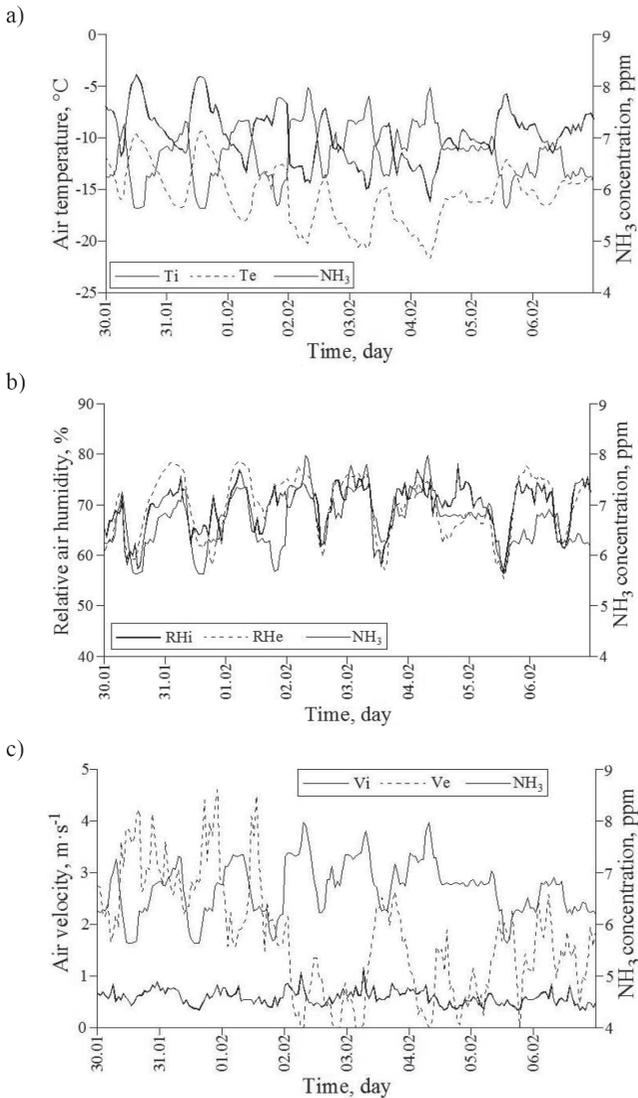


Figure 2. The concentration of ammonia (NH_3) inside the barn in winter from 30 January to 6 February, depending on the air parameters: a – inside air temperature (Ti) and outside air temperature (Te); b – relative inside air humidity (RH_i) and relative external air humidity (RH_e); c – wind speed (V_e) and air movement velocity (V_i)

Spring

The selected fragment of the spring period (19 to 31 May 2012), presented in Figures 3 a, 3 b and 3 c, was characterized by a similar pattern of daily temperature and relative air humidity, with the average wind speed of $1.84 \text{ m}\cdot\text{s}^{-1}$, and the maximum wind speed of $4.67 \text{ m}\cdot\text{s}^{-1}$.

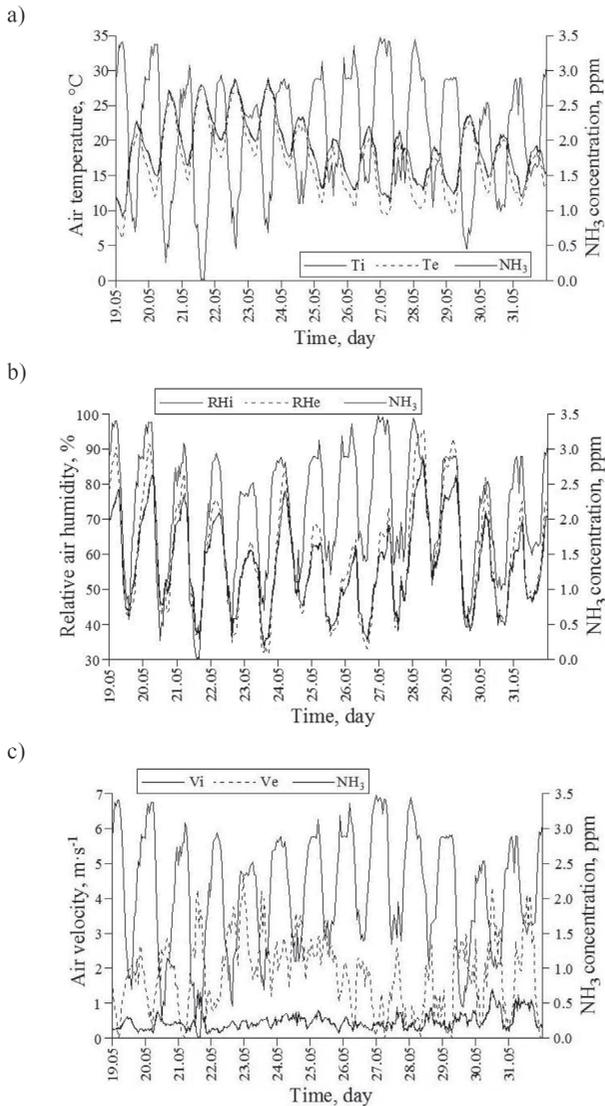


Figure 3. The concentration of ammonia (NH₃) inside the barn in spring from 19 to 31 May 2012, depending on the air parameters: a – inside air temperature (Ti) and outside air temperature (Te); b – relative inside air humidity (RHi) and relative external air humidity (RHe); c – wind speed (Ve) and air movement velocity (Vi)

The reported increase of air temperature above 25°C contributed to the decrease of ammonia levels to the range of 0.5 to 1.0 ppm. The decrease, which lasted from 1 to 5 hours, was caused, similar to the winter period, by the removal of manure from the building. The high wind speed from 11:00 to 17:00 supported air exchange, which resulted in lower ammonia levels.

Summer

The period of summer heat waves, registered for the dates of 5 to 11 July and 18 to 24 June 2012 was distinctive for a cyclical temperature and relative humidity pattern (Figures 4 a, b). With relatively low wind velocity (V_e), the ventilated air movement velocity (V_i) rarely exceeded $0.5 \text{ m}\cdot\text{s}^{-1}$ (Figure 4 c).

Ammonia distribution during the heat waves was insignificant, and from 8:00 to 17:00 its value fell to almost 0.0 ppm .

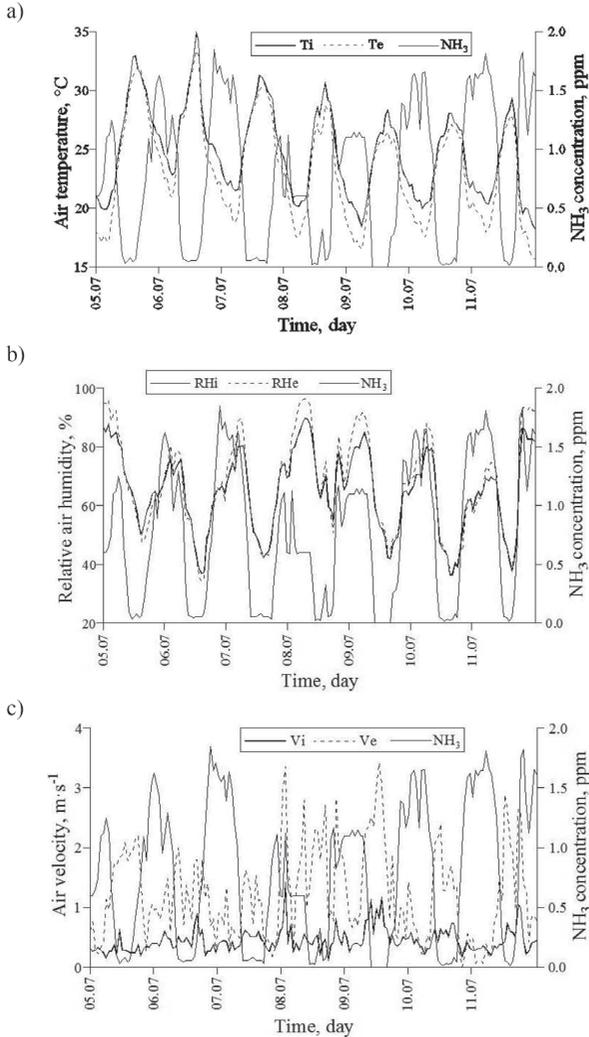


Figure 4. The concentration of ammonia (NH_3) inside the barn in summer from 5 to 11 July 2012, depending on the air parameters: a – inside air temperature (Ti) and outside air temperature (Te); b – relative inside air humidity (RH_i) and relative external air humidity (RH_e); c – wind speed (V_e) and air movement velocity (V_i)

Autumn

This period was characterized by large changeability of weather conditions. In September (24 to 30 September 2012), air temperature was most stable in the afternoon and at nights to increase during the day to the level of 25°C (Figure 5 a). Relative air humidity during the day decreased and during the night it persisted at the level of >75% (Figure 5 b). Wind velocity reached the values of 2.5 to 3.0 m·s⁻¹; inside air velocity remained in the range of 0.2 to 0.8 m·s⁻¹ (Figure 5 c).

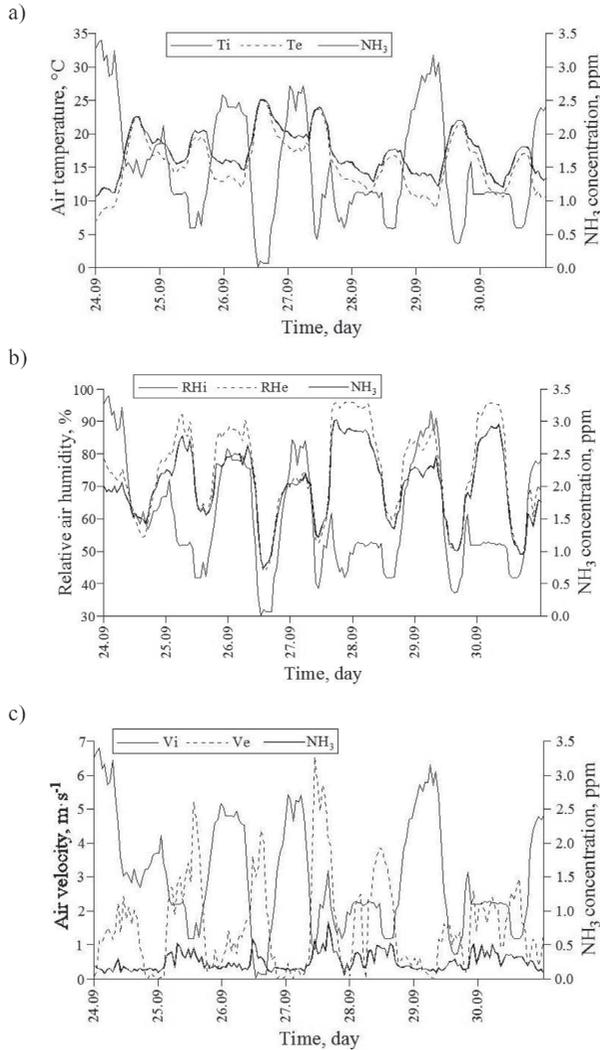


Figure 5. The concentration of ammonia (NH₃) inside the barn in autumn from 24 to 30 September 2012, depending on the air parameters: a – inside air temperature (Ti) and outside air temperature (Te); b – relative inside air humidity (RH_i) and relative external air humidity (RH_e); c – wind speed (V_e) and air movement velocity (V_i)

Table 3. Correlation indexes for particular air parameters ($P < 0.01$ unless otherwise stated)

Research period	Winter		Spring		Summer		Autumn	
	30.01–6.02.2012	19–26.02.2012	18–24.04.2012	19–30.05.2012	5–11.07.2012	18–24.08.2012	24–30.09.2012	18–26.11.2012
Ti	-0.94	-0.86	-0.65	-0.76	-0.70	-0.63	-0.54	-0.52
Te	-0.90	-0.88	-0.79	-0.81	-0.72	-0.68	-0.61	-0.65
RHi	0.56	-0.21	0.67	0.73	0.62	0.61	0.30	0.05 lack
RHe	0.58	-0.16	0.66	0.75	0.60	0.61	0.33	0.32
Vi	0.49	-0.18	-0.44	-0.45	-0.31	-0.55	-0.54	0.02 lack
Ve	-0.47	-0.52	-0.42	-0.63	-0.54	-0.54	-0.56	0.20

Ti – inside air temperature (°C).

Te – outside air temperature (°C).

RHi – relative inside air humidity (%).

RHe – relative external air humidity (%).

Vi – indoor air speed ($\text{m} \cdot \text{s}^{-1}$).Ve – wind speed ($\text{m} \cdot \text{s}^{-1}$).

Statistical analysis of the results from all researched periods revealed that the strongest correlation occurred between air temperature and ammonia concentration; this correlation was most noticeable in winter.

The winter period also showed higher correlation of NH_3 to V_i ($r = -0.94$) than V_e ($r = -0.90$), which was caused by closing the barn. In the remaining periods of the year, when the curtains were lowered and the doors opened, the correlation between NH_3 and T_e was higher than with T_i (Table 3).

The correlations between NH_3 and RH_i and RH_e in particular seasons of the year were very similar. The strongest correlation was visible in spring, moderate in winter and summer; and weak in autumn (Table 3).

The relation between wind velocity (V_e) and the concentration of ammonia for each season of the year was negative and reached average values. The lowest correlation value was noted in winter, which was caused by limited ventilation of the building (Table 3). The correlation with inside air velocity was much different (V_i). In spring and autumn, the correlation remained at an average level. The summer was particular for weak correlation of these parameters ($r = -0.31$), which was the result of opened doors to the barn (Table 3). The lack of significant ventilation barriers enabled fluent exchange of air, which also resulted in lower ammonia concentrations inside the building.

In winter, the correlation between the concentration of ammonia and air movement inside the barn was positive (Table 3). It resulted from internal air rotation (caused by temperature differences across the zones and movement of cattle) in the closed building, where limited ventilation prevented the release of polluted and humid air from the barn.

Statistical analysis conducted for the periods 19 to 26 February and 18 to 26 November revealed only a significant correlation of temperature with ammonia concentration. High humidity of outside and inside air in the studied periods did not affect ammonia concentration (Table 3).

Depending on the changeable weather conditions in the transition periods, curtains were lowered and doors were opened which increased the ventilation potential of the building. As a result, the authors recorded changeable humidity and air movement velocity in the barn, which resulted in no noticeable correlation between the concentration of ammonia and inside air movement.

Discussion

Ammonia concentration fluctuations depend on varying weather conditions, location, periods of the year, different ways of breeding animals, type of building and management system (Pinder et al., 2004; Zhao et al., 2007). The results obtained in the free-stall barn with litter boxes were similar to the average ammonia concentration in similar barns in other EU countries, such as England, the Netherlands, Denmark; but they were significantly lower than in Germany (Groot Koerkamp et al., 1998). Ammonia concentration in the studied barn was definitely at a very low level

when compared to the levels that are considered harmful (more than 20 ppm) (Climatization of Animal Houses, 1984). It must therefore be concluded that ammonia production does not decrease the quality of ventilated air in such types of barns if manure is removed regularly and litter is provided in suitable volumes.

According to Misselbrook and Powell (2005), using straw for bedding can reduce the emissions of ammonia by almost 30% when compared to no-bedding housing. Ammonia is released from excrements as a result of urease activity. This can be limited by the temperature of manure which is replaced by air temperature. The growth of temperature in the summer increases urease activity thus raising ammonia emission from manure (Moreira and Satter, 2006). The research confirms that the level of ammonia in the case of free-stall breeding with litter boxes is mostly affected by air temperature. Significant concentration falls are only possible with open doors.

Wu et al. (2012) state that the concentration of ammonia in naturally ventilated barns is mostly influenced by temperature and air movement. In the researched barn, the concentration of ammonia during the summer, despite high outside temperatures was close to 0.0 ppm. This was mainly due to the increased movement of ventilated air. Such a conclusion was also in line with arguments put forward by Zhao et al. (2007) and Harper et al. (2009) which claimed that increasing air temperature affects the growth of ammonia emissions, which are later diluted by the movement of air. Open curtains in the studied barn supported the increase of air in the summer season, which prevented the growth of ammonia concentration in the barn. This can be confirmed by the analysis of data obtained for the winter period, especially for severe frosts. In this case, limited ventilation contributed to the increase of ammonia concentration by approx. 8.0 ppm. With respect to the annual average concentration of 2.73 ppm, this was a very high value. This fact can be confirmed by the study conducted by Kang and Lee (2008), according to which excessive reduction of ventilation inside the building leads to the deterioration of indoor air quality. That can be also confirmed by the results of the study obtained during the winter period, when the building was closed. Higher ammonia concentrations were the result of limited barn ventilation (Osario et al., 2009).

Simsek et al. (2012) stated that maximum concentration of ammonia in barns can be recorded between 00:00 and 02:00. This is the case because of reduced air movement and lower animal activity. In turn, the lowest gas concentration is observed from 12:00 to 14:00. In the case of the studied barn, summer nights were characterized by an increase in ammonia concentration to 2.0 ppm and maximum values were reached around midnight. During the day, however, the fall of ammonia concentration could be noted from 08:00 to 17:00.

Morning manure removal coincided in time with the increase of temperature and decrease in relative humidity, most likely related to the location of the building along the east-west axis. The lack of manure meant that although the temperature was supporting the release and maintenance of ammonia in the air, the concentration of this gas did not go up. Low relative air humidity, open curtain walls and doors increase the exchange of air, which led to the situation when manure accumulated during the day did not increase ammonia levels in the barn.

According to Moreira and Satter (2006), increasing the frequency of cleaning manure corridor does not affect the oxidation of nitrogen (ammonia release) in a significant way. This is confirmed by the study presented in this paper. In the summer, manure corridors were cleaned twice a day, but only once in winter. What was definitely more important was the fact of closing or opening the barn. The decrease of ammonia concentration during corridor cleanup in winter was 2.5 ppm on average and in the summer approx. 2.0 ppm.

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