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Short Communication

The Impact of Natural Ventilation on Ammonia Emissions from Free Stall Barns

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Abstract

This paper presents results of research on ammonia concentrations and emissions from a free stall barn to the atmosphere in the course of one year, with particular attention to the summer and winter periods. The rate of ammonia emissions was influenced by the amounts of ventilated air, which were the highest in summer period and lowest in winter. The obtained results were lower than the values provided by other authors, which points out the need for conducting further detailed studies on ammonia emissions from various types of free stall barns and cattle breeding systems.

Keywords: ammonia, emissions, concentration, free stall barn, natural ventilation

Introduction

Ammonia from livestock production is an important factor contributing to air pollution, including acid rain, eutrophication of waters, acidification of soils or reduction of plant biodiversity [1, 2], and thereby also contributing to soil erosion [3].

The combination of ammonia with other air pollutants may lead to the emergence of respiratory and cardiovascular diseases [4].

According to Pinder et al. [5], the majority of ammonia emissions are produced by cattle farms. Ammonia is mainly emitted by manure, liquid manure, slurry, bedding, and feed for cattle [6, 7].

Highly productive cows, in addition to ensuring appropriate circadian rhythm [8], need plenty of fresh air of suitable quality, because insufficient amounts of oxygen slow down their metabolism, which in turn affects milk production [9].

The concentration of ammonia in barns is highly variable and depends on the type of building, its volume, ventilation system, livestock density, barn maintenance system, and the frequency of cattle manure removal [10]. Ammonia emissions to the atmosphere depend on the amount of produced ammonia and the size of air exchange between a building and the atmosphere [11, 12]. Specialist literature presents a number of models for ammonia emissions from agricultural buildings, depending on animal types and breeding systems [13-15]. However, in many cases the modelled calculation values differ significantly from the values obtained in field research [16], which leads us to conclude that the emission rate assumed for the needs of estimating air pollution from barns is not very accurate.

The aim of our study was to define the impact of natural ventilation in a free stall barn on the size of ammonia emissions to the atmosphere throughout the year. Particular attention has been drawn to the summer and winter periods, when cows have the greatest ventilation requirements. The study included measurements of temperature, humidity, air flow velocity in the barn and outside the barn, and ammonia concentration. Based on the obtained results and the size of air exchange in the barn, it was possible to calculate ammonia emissions to the atmosphere, which were compared to results obtained in other studies.

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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	$m^2 \cdot cow^{-1}$	9
Usable cubage per animal	$m^3 \cdot cow^{-1}$	53
Total area of outside walls	m^2	992
Curtains area	m^2	207
Door area	m^2	54
Ridge ventilation area	m^2	32.5

Materials and Methods

Our research was conducted in 2012 in two similar free stall barns for 176 dairy cattle of Holstein Friesian breed. In one of the barns, the measurements were conducted continuously; in the other, transient measurements were made. The aim was to verify the repetitiveness of the results. The analysis was conducted from January to March (winter) and June to August (summer).

In the case of continuous research, the barn of 1,580 m^2 usable floor area was located in the village of Kobylany, Małopolska Province (N: 50º8' 59" E: 19º45' 12"). It was oriented along the east-west axis and 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.

Manure was removed mechanically from the concrete floor of manure corridors twice a day directly to the manure pad located on the west side of the building. The lying boxes were laid with straw once a day. The cattle were fed according to the total mixed ration method with unchanged ingredients throughout the year.

The measurement points were located in the barn 1 meter above the ground. The sensors measured temperature, air velocity, and ammonia concentration. 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. All measurements were conducted with a frequency of 6 minutes and recorded automatically.

Air movement velocity was measured with the help of HD 103T sensors, produced by Delta Ohm. Their measurement range was 0-5 $m \cdot s^{-1}$. They had measurement accuracy of 0.04 $m \cdot s^{-1}$ in the range of 0-0.99 $m \cdot s^{-1}$ and measurement accuracy of 0.02 $m \cdot s^{-1}$ in the measurement range of 1-5 $m \cdot s^{-1}$. Temperature and relative air humidity were measured with the help of integrated sensors LB-710 produced by Label, with the measurement range of -40 to +85ºC. The concentration of ammonia was registered with the help of a Unitox IV gas detector with the measurement range of 0-100 ppm and measurement accuracy of 0.5 ppm. Transient measurements in the other barn were conducted with the help of CHY 361 anemometers and Multiwarn Draeger, a device used to measure gasses in the air.

Ammonia emissions from the barn were calculated as the product of ventilation rate and concentration of ammonia in the barn [17, 18]. Ventilation exchange, which was influenced not only by the power of wind but also thermal buoyancy [15], was calculated with the help of a formula developed by Kiwan et al. [11]:

$$Q_{total} = \sqrt{(Q_{windforces})^2 + (Q_{thermalbuoyancy})^2}$$

...where: Q_{total} – total ventilation rate, ($m^3 \cdot s^{-1}$), $Q_{windforces}$ – the ventilation rate due to wind forces, ($m^3 \cdot s^{-1}$), $Q_{thermalbuoyancy}$ – the ventilation rate due to thermal buoyancy ($m^3 \cdot s^{-1}$).

The particular components of the model were calculated with the help of the following formulas:

1. Ventilation rate due to thermal buoyancy [19]:

$$Q = \frac{C_d \cdot A}{3} \cdot \sqrt{g \cdot H \cdot \frac{\Delta T}{T_i}}$$

...where: C_d – discharge coefficient (0.86), A – area of the opening, (m^2), g – gravitational acceleration, ($m \cdot s^{-2}$), H – height of the openings, (m); T_i – indoor air temperature, (K); $\Delta T = T_i - T_e$, T_e – outdoor air temperature, (K).

2. Ventilation rate due to wind forces [11]:

$$Q = E \cdot A \cdot V$$

...where: E – effectiveness of openings (0.35), A – free area of inlet openings, (m^2), V – wind velocity, ($m \cdot s^{-1}$).

Results

During the winter period, the exchange of ventilated air was limited because the main door was closed and the curtains in longitudinal walls were raised in order to protect the cows from excessive cooling. During that time of year, the wind was very strong and despite raised curtains it increased inside air velocity to the level of 0.2 $m \cdot s^{-1}$. As a result, T_i and T_e differed significantly over the 24-hour daily cycle.

On the other hand, during the registered summer period of high temperatures, T_i and T_e did not differ significantly over the 24-hour daily cycle. With significantly lower wind velocity (V_e) in winter, the ventilated air movement velocity (V_i) rarely exceeded 0.5 $m \cdot s^{-1}$.

Averaged results of temperature and air movement velocity for the summer and winter of 2012 are presented in Table 2.

The values presented in Table 2 were used as a basis for calculating ventilation rate for the barn. The calculations take into account the fact that the door and curtains were open during the entire summer period. In winter, the curtains

Table 2. Air parameters for select study periods.

Month	T_i	T_e	V_i	V_e
	ºC	ºC	$m \cdot s^{-1}$	$m \cdot s^{-1}$
January	0.95	-1.47	0.28	2.70
February	-0.93	-6.50	0.27	2.15
March	9.36	5.06	0.23	2.35
June	19.69	17.88	0.39	1.61
July	21.90	20.20	0.38	1.55
August	21.15	19.36	0.37	1.40

T_i – monthly average inside air temperature
T_e – monthly average outside air temperature
V_i – monthly average indoor air speed
V_e – monthly average wind speed

were closed but the door was open from time to time when the manure was being removed or feed was being delivered.

During the studied period of one year, an average monthly ammonia concentration in the barn was at the levels presented in Table 3. During severe frosts, when manure corridors were cleaned only once a day, ammonia concentration reached the maximum levels of 8.0 ppm. In turn, average summer values of ammonia concentration were at the level of 1.0-1.5 ppm. During extreme heat waves, when the temperature exceeded 25ºC, ammonia concentration reached the level of approx. 0.5 ppm.

Discussion

Ventilation efficiency influences pollution emissions from buildings, including ammonia emissions [20]. The recommended ventilation rate for dairy cattle provided in specialist literature varies and the values differ significantly. Seedorf et al. [20] makes a distinction between ventilation requirements in the barn during the winter period: 67 $m^3 \cdot h^{-1} \cdot AU^{-1}$ and during the summer period: 417 $m^3 \cdot h^{-1} \cdot AU^{-1}$. According to Pajumägi et al. [16], the minimum rate of air exchange in the barn should range from 0.15 to 0.35 $m^3 \cdot h^{-1}$ per 1 kg of cattle body weight; while the maximum rate of air exchange should not exceed 10 h^{-1}.

In barns ventilated naturally, it is difficult to estimate air exchange rate and each of the known methods has certain limitations and does not yield a fully accurate result [14]. Pajumägi et al. [16] are probably right when criticizing the theoretical ventilation efficiency calculated on the basis of thermal and humidity balance. According to the calculations performed by the authors with the method described above, the values of ventilation rate varied in the range 530 to 2,300 $m^3 \cdot h^{-1} \cdot cow^{-1}$ in the winter period. Those values seem to be completely unrealistic. The obtained results of ventilation rate calculation, determined with the help of formulas presented in the methodology and taking into consideration wind speed and thermal buoyancy confirm that this method is more accurate and reliable.

Wu et al. [21] state that the concentration of ammonia in naturally ventilated barns is mostly influenced by temperature and air movement. 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. In the summer, the concentration of ammonia in the studied barns was on average 1.25 ppm. This was mainly caused by the movement and exchange of air, which was determined to be 3 h^{-1} for the winter period and 12 h^{-1} for the summer. Such a conclusion was also in line with conclusions put forward by Zhao et al. [12] and Harper et al. [22], who claimed that increasing air temperature affects the growth of ammonia emissions, which are later diluted by the movement of air. Herbut et al. [23], however, point out the fact that air exchange in barns with a natural ventilation system is complex and depends on a number of factors. As a result, the real exchange rate of ventilated air may be lower; thus the emission of ammonia may also be lower.

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. The conclusions presented above can be confirmed by the study conducted by Kang and Lee [24], according to which excessive reduction of ventilation inside the building leads to the deterioration of indoor air quality.

The total annual ammonia emission to the air from the studied barn was 564.8 kg NH_3. The highest value was noted for the summer (218.0 kg NH_3) and the lowest in winter (41.2 kg NH_3), when the exchange of ventilated air inside the barn was significantly limited. The calculated yearly emissions from the barns was 8.79 $g \cdot d^{-1} \cdot cow^{-1}$, including 2.57 $g \cdot d^{-1} \cdot cow^{-1}$ for the winter period and 13.46 $g \cdot d^{-1} \cdot cow^{-1}$ for the summer.

Monteny and Erisman [14] suggested that the emissions of ammonia for a free stall barn with natural ventilation are 25 $g \cdot d^{-1} \cdot cow^{-1}$. In turn, Harper et al. [22] calculated that the emissions for 2 free stall barns with boxes covered by sand is 16.77 $g \cdot d^{-1} \cdot cow^{-1}$ and 7.89 $g \cdot d^{-1} \cdot cow^{-1}$ in winter; and 33.22 $g \cdot d^{-1} \cdot cow^{-1}$ and 38.42 $g \cdot d^{-1} \cdot cow^{-1}$ in summer. The research conducted by Ngwabie et al. [17] covering the months of February and May determined the emissions of ammonia at the level 9.6-36 $g \cdot d^{-1}$. However, this could have been the result of the breeding system: the cows lied on rubber mats covered with peat.

The coefficients of ammonia emissions used for evaluating air pollution in Poland determined for dairy cattle are 27.8 kg $NH_3 \cdot cow^{-1} \cdot year^{-1}$; and for high-yield cows kept on shallow litter, it is 32.42 kg $NH_3 \cdot cow^{-1} \cdot year^{-1}$ [25]. Based on the conducted research, the authors conclude that these values are highly overestimated.

Moreover, the authors do not agree with Mielcarek [25] that ammonia emissions from livestock buildings are easy

Table 3. Ammonia concentration, calculated ventilation rate, and monthly barn ammonia emissions in 2012.

Month	Average NH_3 concentration in barn air	Average ventilation rate in barn	Monthly average NH_3 emission from barn
	ppm (mg·m^{-3})	m^3·h^{-1}	kg NH_3
January	2.98 (2.09)	7,083	11.0
February	3.49 (2.45)	10,335	17.6
March	2.71 (1.90)	8,912	12.6
April	1.25 (0.87)	98,860	62.4
May	1.29 (0.91)	106,687	71.9
June	1.40 (0.98)	114,811	81.2
July	1.13 (0.79)	111,346	65.5
August	1.22 (0.86)	111,872	71.3
September	1.33 (0.93)	117,752	79.2
October	1.41 (0.98)	93,403	69.0
November	2.83 (1.97)	7,905	11.3
December	2.46 (1.71)	9,196	11.8

to estimate. Polish and international specialist literature has noted a number of works concerning ammonia emissions to the atmosphere, yet the presented research results seem to be very divergent. This may be due to the variety of adopted methods of calculating ventilation rate, different meteorological conditions, locations, cattle breeds, and maintenance systems, or technological solutions in barn structure. These are the factors that primarily impact the size of ammonia emissions from free stall barns into the atmosphere. Therefore, it is necessary to analyze and verify various types of existing barns focussing on ammonia concentrations and the real efficiency of their ventilation systems.

Conclusion

Presented results of the research show that the level of ammonia in the case of free stall breeding with litter boxes is mostly affected by air temperature and exchange rate of ventilated air.

Taking into account wind speed and thermal buoyancy in the calculations of the ventilation allows for precise determination of it size.

The coefficients of ammonia emissions used for evaluating air pollution in Poland determined for dairy cattle are highly overestimated.

The size of ammonia emissions from free stall barns into the atmosphere depends on many factors, so it is necessary to accurately analyze various types of existing barns focussing on ammonia concentration and real efficiency of their ventilation systems.

References

1. SAHA C.K., ZHANG G., NI J. Airflow and concentration characterisation and ammonia mass transfer modelling in wind tunnel studiem. Biosyst Eng. **107**, 328, **2010**.
2. TEYE F.K., HAUTALA M., PASTELL M., PRAKS J., VEERMAE I., POIKALAINEN V., PAJUMÄGI A., KIVINEN T., AHOKAS J. Microclimate and ventilation in Estonian and Finnish dairy buildings. Energ. Buildings **40**, 1194, **2008**.
3. HERNIK J. Protecting Poland. GEO: Connexion **6**, (1), 38, **2006**.
4. MOREIRA V.R., SATTER L.D. Effect of Scraping Frequency in a Freestall Barn on Volatile Nitrogen Loss from Dairy Manure. J. Dairy Sci. **89**, 2579, **2006**.
5. PINDER R.W., PEKNEY N.J., DAVIDSON C.I., ADAMS P.J. A process-based model of ammonia emissions from dairy cows: improved temporal and spatial resolution. Atmos. Environ. **38**, 1357, **2004**.
6. AGUERRE M.J., WATTIAUX M.A., HUNT T., LARGET B.R. Effect of dietary crude protein on ammonia-N emission measured by herd nitrogen mass balance in a freestall dairy barn managed under farm-like conditions. Animal. **4**, (8), 1390, **2010**.
7. MISSELBROOK T.H., POWEL J.M. Influence of Bedding Material on Ammonia Emissions from Cattle Excreta. J. Dairy Sci. **88**, 4304, **2005**.
8. ADAMCZYK K., SŁANIA A., GIL Z., FELENCZAK A., BULLA J. Relationships between milk performance and behaviour of cows under loose housing conditions. Ann Anim Sci. **11**, (2), 283, **2011**.
9. HERBUT P., ANGRECKA S. Ammonia concentrations in a free-stall dairy barn. Ann Anim Sci. **14**, (1), 153, **2014**.
10. KARANDUŠOVSKÁ I., MIHINA Š., LENDELOVÁ J., BOĎO Š., PÁLEŠ D., PITERKA P., BOŠANSKÝ M. Investigating the impact of manure removal frequency on the amount of produced pollutants in cattle housing. J Cent Eur Agr. **14**, (4), 1262, **2013**.
11. KIWAN A., BERG W., BRUNSCH R., ÖZCAN S., MÜLLER H.J., GLÄSER M., FIEDLER M., AMMON C., BERCKMANS D. Tracer gas technique, air velocity measurement and natural ventilation method for estimating ventilation rates through naturally ventilated barns. Agr. Eng. **14**, (4), 22, **2012**.
12. ZHAO L.Y., BRUGGER M.F., MANUZON R.B., ARNOLD G., IMERMAN E. Variations in air quality of new Ohio dairy facilities with natural ventilation systems. Appl. Eng. Agric. **23**, (3), 339, **2007**.
13. GILLILAND A., APPEL K.W., PINDER R.W., DENNIS R.L. Seasonal NH3 emissions for the continental united states: Inverse model estimation and evaluation. Atmos. Environ. **40**, 4986, **2006**.
14. MONTENY G.J., ERISMAN J.W. Ammonia emission from dairy cow buildings: a review of measurement techniques, influencing factors and possibilities for reduction. Neth. J. Agr. Sci. **46**, 225, **1998**.
15. ZHANG G., STRØM J.S., LI B., ROM H.B., MORSING S., DAHL P., WANG C. Emission of Ammonia and Other Contaminant Gases from Naturally Ventilated Dairy Cattle Buildings. Biosyst Eng. **92**, (3), 355, **2005**.
16. PAJUMÄGI A., POIKALAINEN V., VEERMÄE I., PRAKS J. Spatial distribution of air temperature as a measure of ventilation efficiency in large uninsulated cowshed. Build. Environ. **43**, 1016, **2008**.

17. NGWABIE N.M., JEPPSSON K-H., GUSTAFSSON G., NIMMERMARK S. Effects of animal activity and air temperature on methane and ammonia emissions from a naturally ventilated building for dairy cows. Atmos. Environ. **45**, 6760, **2011**.
18. SAPOUNAS A.A., CAMPEN J.B., SMITS M.C.J., VAN DOOREN H.J.C. Simulating the effect of forced pit ventilation on ammonia emission from a naturally ventilated cow house with CFD. In 4th European Conference on Precision Livestock Farming, 81-89: Wageningen Academic Publishers, **2009**.
19. AWBI H.B. Air movement in naturally-ventilated buildings, Renew. Energ. **8**, 241, **1996**.
20. SEEDORF J., HARTUNG J., SCHRÖDER M., LINKERT K.H., PEDERSEN S., TAKAI H., JOHNSEN J.O., METZ J.H.M., GROOT KOERKAMP P.W.G., UENK G.H., PHILLIPS V.R., HOLDEN M.R., SNEATH R.W., SHORT J.L., WHITE R.P., WATHES C.M. A Survey of Ventilation Rates in Livestock Buildings in Northern Europe. J. Agr. Eng. Res. **70**, 39, **1998**.
21. WU W., ZHANG G., KAI P. Ammonia and methane emissions from two naturally ventilated dairy cattle buildings and the influence of climatic factors on. ammonia emissions. Atmos. Environ. **61**, 232, **2012**.
22. HARPER L.A., FLESCH T.K., POWELL J.M., COBLENTZ W.K., JOKELA W.E., MARTIN N.P. Ammonia emissions from dairy production in Wisconsin. J. Dairy Sci. **92**, 2326, **2009**.
23. HERBUT P., ANGRECKA S., NAWALANY G. Influence of wind on air movement in a free stall barn during the summer period. Ann Anim Sci. **13**, (1), 109, **2013**.
24. KANG J.H., LEE S.J. Improvement of natural ventilation in a large factory building using a louver ventilator. Build. Environ. **43**, (12), 2132, **2008**.
25. MIELCAREK P. Verification of emission coefficient of ammonia and greenhouse gases from livestock production. Inż. Rol. **4**, (139), 267, **2012** [In Polish].