Emission of harmful gases from animal production in Poland

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Abstract The aim of the study was to present the scale of greenhouse gas emissions from animal production, and to provide test results from different housing systems. In three free stall buildings, two with slurry in deep channels and one with cattle in cubicles staying on shallow litter concentration of ammonia and carbon dioxide were measured in summer season by using dedicated equipment from Industrial Scientific Research. Air exchange was calculated on the base of balance carbon dioxide method. This method was used in order to estimate the air flow rate. Concentrations of ammonia and CO_2 were measured as the base for air exchange and ammonia emission rates. Ammonia emissions were product of ammonia concentration and air exchange rate. Temperature and relative humidity were measured to establish microclimate conditions in buildings tested to show the overall microclimatic situation in buildings. Differences between ammonia emission rates were observed in both housing systems. The highest ammonia emission rate was equal to 2.75 $g \cdot h^{-1} \cdot LU^{-1}$ in well-ventilated cattle barn with the largest herd size.

Highlights

- A comparative analysis of the results available in the literature has shown and confirmed significant lower ammonia emissions when using litters than with no litter housing.
- In system with bedding twice lower level of air exchange rate than recommended by standards caused much high level of ammonia concentration and quite high ammonia emission, although lower than from housing without litter.
- Ammonia emission from cattle barn in the litter-free system was about twice as high as compared to available data from the literature, which could have been caused by the higher ventilation index in line with the values recommended in the standards for cattle breeding.
- The usefulness of the carbon dioxide balance method for estimating air exchange from loose housing barns with roof ridge ventilation was confirmed.

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Table 1 Results of model analysis of typical dairy farms with feed production on the farm

Housing system	Tied-up	Tied-up (2nd type)	Free stall	Free stall (2nd type)
Basic herd size cattle	100	100	200	200
	142	142	284	284
Milk yield, l	5000	5000	6000	6000
CH_4 losses (eq.CO_2), t	344.5	347.8	834.4	819.9
Emission $CH_4 \cdot kg \cdot cow \cdot year^{-1}$	4.05	4.16	4.65	4.84
N_2O losses (eq. CO_2), t	663.0	645.3	1500.7	1329.0

Source: own elaboration based on Gridnev et al. (2014)

Introduction

Milk and meat production are finally balanced with an environmental and animal welfare conditions to minimize negative influence for the environment. Major amount of nitrogen are leaching from livestock production to the environment.

According to the inventories, agriculture is a significant source of greenhouse gases (GHG) (Roman et al., 2019). In 2015, the EU agricultural sector emitted 3751 kt of ammonia and was responsible for 94% of total ammonia emissions (Crippa et al., 2018; EUROSTAT, 2020). Poland is one of the most important contributors to nitrogen atmospheric emissions in the Baltic Sea Region (EUROSTAT, 2020).

Moreover, significant amounts of harmful ammonia gas are derived from livestock production. Cattle are responsible for 70% of total greenhouse gas emissions (Philippe & Nicks, 2015).

There is a lack of data about ammonia emissions from cattle barns from central Europe. Ammonia emissions differ depending on climate zone, housing system, manure management (Baldini et al., 2016), type of feed (Bougouin et al., 2016) and animal breed.

Air temperature in the barn is the most important factor affecting ammonia emissions (Sanchis et al., 2019). Literature analysis shows that authors from across Europe describe the problem of harmful gases in connection with animal production. We have some works from Poland Herbut and Angrecka (2014) and Pietrzak (2006)—and abroad—Demmers et al. (1998), Dore et al. (2004), Jungbluth et al. (2001), Mohn et al. (2018) and Poteko et al. (2019).

Tied-up cattle barns were under observation using measurements of ventilation rate and concentration of harmful ammonia gas (Karłowski et al., 2008). The measurements were carried out of ammonia emissions from manure plate by using micrometeorological passive dosimetry method (Ferm et al., 2005; Marcinkowski, 2010).

There were prepared by Russian scientists' table of harmful gas emissions, including methane and forms of nitrogen from different cattle housing systems in intensive production in cold climate (Gridnev et al., 2014) (Table 1).

Ammonia emissions from systems with natural ventilation depend heavily on the efficiency of the ventilation system; the more effective it is, the greater the probability of higher emissions. Bougouin described negative impact of milk production on NH_3 emission that milk yield had on NH_3 emissions (Bougouin et al., 2016).

Demmers indicates that the CO_2 balance method demands not only the presence of animals inside the building but also detailed knowledge about CO_2 quantities. According to this information, carbon oxide could be a better tracer gas because of its features: its density is almost the same as the air and it can be measured by continuously working data analyzer, and is inertive enough and has low background concentration.

Table 2 shows the amounts of chosen GHG emissions according to Krawczyk and Walczak (2010). There were balance chambers used with steady thermal-humidity conditions and a steady air exchange rate. In this work, ammonia emissions tested from cattle barns with slurry and with solid manure in shallow boxes were presented.

Table 2 Gaseous emissions from housing systems of technological groups (kg year^{-1}•LU^{-1})

| | Housing system | | | | | |
	Littered straw	Littered sawdust	Deep litter straw	Deep litter sawdust	Without litter	Slotted
Dairy cows						
Water vapor	3456.4	3562.1	3732.6	3862.8	3956.4	x
Carbon dioxide	2664.8	2545.3	2989.4	2844.1	2764.8	x
CH$_4$	108.4	112.91	123.53	126.32	119.2	x
N$_2$O	0.032	0.045	0.062	0.073	0.416	x
Heifers						
Water vapor	3110.4	3456.1	3567.1	3595.9	3645.2	3723.7
Carbon dioxide	1944.6	1823.8	2078.3	1924.5	1998.2	2129.7
CH$_4$	56.3	57.4	79.32	84.27	66.73	67.58
N$_2$O	0.01	0.016	0.019	0.021	0.022	0.024
Calves						
Water vapor	x	x	1941.43	2059.2	X	2178.4
Carbon dioxide	x	x	1108.23	1046.3	x	987.8
CH$_4$	x	x	21.2	24.47	x	19.6
N$_2$O	x	x	0.002	0.004	x	0.006

Source: own elaboration based on Krawczyk and Walczak (2010)

Methods

Determination of emissions from buildings with natural ventilation demands measurements of gas concentrations and air exchange rates. Also, CFD methods are available for ammonia emission modelling, but they still need to develop (Bjerg et al., 2013a, b; Yi Q et al., 2019a, b). In this study, levels of ammonia and carbon dioxide concentrations were tested both inside and outside the 3 boxed livestock buildings: one with shallow litter and two with slurry in deep channels.

Both gas concentration and air exchange rate should be measured, especially for naturally ventilated livestock buildings as determination of it is problematic. In such cases, tracer gas methods are used (as a type of balance method). Nosek et al. (2020) confirmed that tracer gas method is very useful for ventilation rate estimation.

For example, some researchers used CO$_2$, SF$_6$ or cryptone 85 as tracer gases (Müller et al. 2007; Kiwan et al., 2012).

Edouard et al. (2016) used tracer gas method as well as moisture balance method. Indicators of CO$_2$ emissions by livestock animals and water vapor are not constant and depend on the animals, age and diet. In our study, the CO$_2$ balance method was used.

The methods in our research consisted of the following stages:

(1) Measurements of ammonia concentrations in few points inside cattle barns (S) by using gas concentration meters, made by company Industrial Scientific Co.
(2) Estimation of air exchange rate (V) using validated method of carbon dioxide balance. For metabolic emission of carbon dioxide by one LU, average values were used W$_{CO2}$ = 220 g·h^{-1}·LU^{-1} according to the Institute of Zootechnics in Cracow.
(3) Calculation of ammonia emission (E).

Ammonia emission (E) was equal product of air exchange rate (V) and ammonia concentration (S):

$$E = V \cdot S \tag{1}$$

where:

E—ammonia emission from building [g·h^{-1}·LU^{-1}],
V—air exchange rate in building [m^3·h^{-1}·LU^{-1}],
S—average ammonia concentration from measurement points, reduced by the concentration of this gas in the air flowing into the cattle barn [ppm, converted into g m^{-3}].

The ventilation rate was calculated using the carbon dioxide balance method from the equation:

$$V = \frac{WCO_2}{C_{inside} - C_{outside}} \left[m^3 \cdot h^{-1} \right] \qquad (2)$$

where:

V—air exchange rate in building $[m^3 \cdot h^{-1} \cdot LU^{-1}]$,

W_{CO2}—metabolic emission of carbon dioxide by one LU $[g \cdot h^{-1} \cdot LU^{-1}]$,

C_{inside}—average CO_2 concentration inside cattle barn—average from measurement points measured in particular time [ppm, converted into $g \cdot m^{-3}$],

$C_{outside}$—average CO_2 concentration in air inflowing into the building [ppm, converted into $g\ m^{-3}$].

Finally, ammonia emission was equal:

$$E = \frac{WCO_2}{C_{inside} - C_{outside}} \cdot S \qquad (3)$$

where:

E—ammonia emission from building $[g \cdot h^{-1} \cdot LU^{-1}]$; other marks supra.

Additionally, temperature and relative humidity were measured using thermo-hygrometers.

The following measurement equipment was used:

– 4 multi-gas monitors for CO_2 and NH_3 concentrations. They were mobile, with own memories, type MX6, American producer Industrial Scientific,

– 4 thermo-hygrometers LB-710 (TH-5, TH-6, TH-7, TH-8), connected with concentrator LB-731 for data collecting.

Results

A short characteristic of herd like herd size and system of removing manure is shown in Table 3. The annual milk yield was at the range from 7000 to 9500 l in the extra class for cows Holstein–Friesian breed. In two boxed cattle barns with slatted floors, the slurry was collected in deep manure channels and pumped out from them. Additionally, robotic manure scrapers were regularly removing the slurry from slatted floors making them more clear. In all buildings, natural light was from the windows in the walls and from roof ridge gap. Table 4 presents the statistical values of ventilation rates (air exchange rates) and estimated diurnal average ammonia emissions from cattle barns tested during the summer period (June–July). Temperature and air relative humidity were measured separately.

The obtained results of harmful gas emission which is ammonia depend on the effectiveness of the ventilation.

The highest level of ammonia emission was observed from cattle barn with deep slurry channels and with the highest ventilation rate which amounted 2.75 $(g \cdot h^{-1} \cdot LU^{-1})$. In contrary, the lowest emission

Table 3 General characteristics of tested objects

No	LU	Housing type	Ventilation system	Unitary cubage	Average milk yield of herd; litres•cow^{-1} year^{-1}	Manure removing system
3	50	Free stall boxed, shallow litter (straw), solid floor	Gravitational ventilation, air inflow through wall openings; outflow through roof ridge gap	107.8	7000	2 kg of straw per 1 LU, littered daily; hydraulic manure scrapers, twice a day
2	140	Free stall, boxed, without litter	Gravitational ventilation, air inflow through wall openings—mobile curtains; outflow through roof ridge gap	70.64	8500	Slurry in deep channels; robotic manure scraper 5 times per day
3	83	Free stall, boxed, without litter, slatted floor	Gravitational ventilation, air inflow through wall openings; outflow through roof ridge gap	74.00	9500	Robotic manure scraper 3 times per day

Source: own study

Table 4 Gaseous emissions from housing systems of objects tested ($kg \cdot year^{-1} \cdot LU^{-1}$)

No. of cow-shed	Statistical value	Temperature inside	Relative humidity outside	Relative humidity inside	Air exchange rate (V)	NH_3	NH_3 emission*	CO_2
		[°C]	[%]	[%]	[$m^3 \cdot h^{-1} \cdot LU^{-1}$]	[ppm]	[$g \cdot h^{-1} \cdot LU^{-1}$]	[ppm]
1	Mean	23.92	73.86	73.3	262.2/203.2*	5.22/11.31*	1.73/2.64*	792/1132*
	Min	19.53	38.64	52.12	160/84.9	1/2*	0.2/0.27*	300/500*
	Max	27.3	96.7	87.4	3653.5/1826.7*	17/18*	3.6/37.03*	500/1733*
2	Mean	23.69	48.14	58.31	401.76	11.97	2.75	845.5
	Min	18.59	18.4	21.28	170.4	1	0.78	450
	Max	30.61	67.65	77.34	3784.3	23	3.73	1380
3	Mean	17.72	59.25	69.32	399.65	6.16	1.47	665
	Min	11.94	38.15	56.54	167.59	1	0.59	300
	Max	21.85	95.13	90.21	3687.1	19	6.95	1500
Recommendation (Collective work 2005)		Optimal 8–16	-	Optimal 70 max. 80	450	Max. 20		Max. 3000

*Day/night, source: own study

1.47 ($g \cdot h^{-1} \cdot LU^{-1}$) was observed in a cattle barn with the lowest cubage.

According to the above-presented table, the values of NH_3 and CO_2 emission levels were estimated. The established high, average and low levels of gas emissions were created, as multiple values of 7 ppm for NH_3 and 1000 ppm for CO_2. Created levels were dependent on the recommended limits of NH_3 that equal 20 ppm and CO_2 equal 3000 ppm. Using the estimated levels, correlation of environmental parameters in reference to the gas emissions from cattle houses was conducted. The ANOVA method was chosen as a tool for statistical analysis. During the statistical analysis, the temperature inside, relative humidity outside and humidity inside were correlated to the gas emissions. The results of temperature compared with the CO_2 and NH_3 levels were presented in Fig. 1.

During the statistical analysis, the expected marginal mean of temperature influence to CO_2 and NH_3 emission density was specified. In the case of temperature impact on the CO_2 emission level, the significance value (p) was below than critical level of 0.05 (5%), and the statistical empirical value $F(1, 846) = 27.494$. The statistical analysis of the temperature influencing the NH_3 emission level delivers that
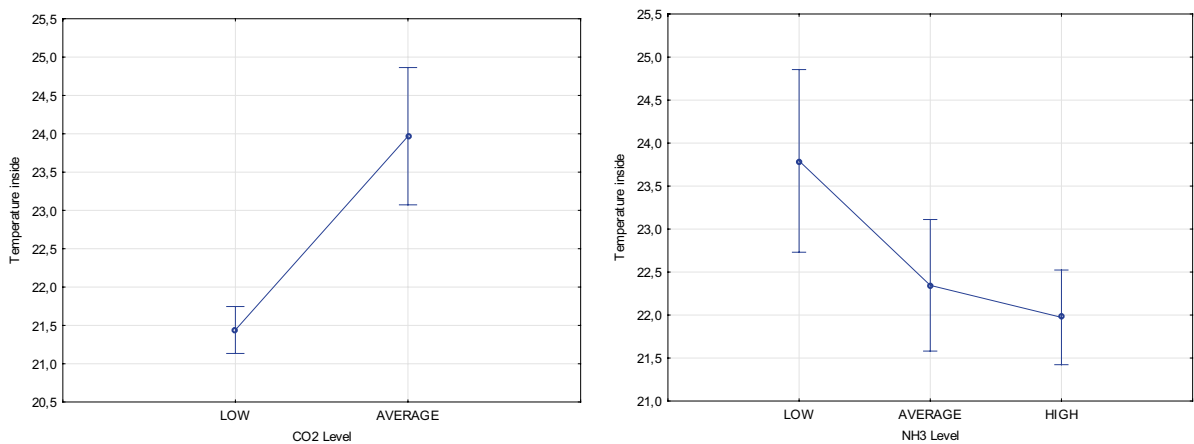

Fig. 1 The results of temperature comparison concerning CO_2 and NH_3 levels. Source: own study
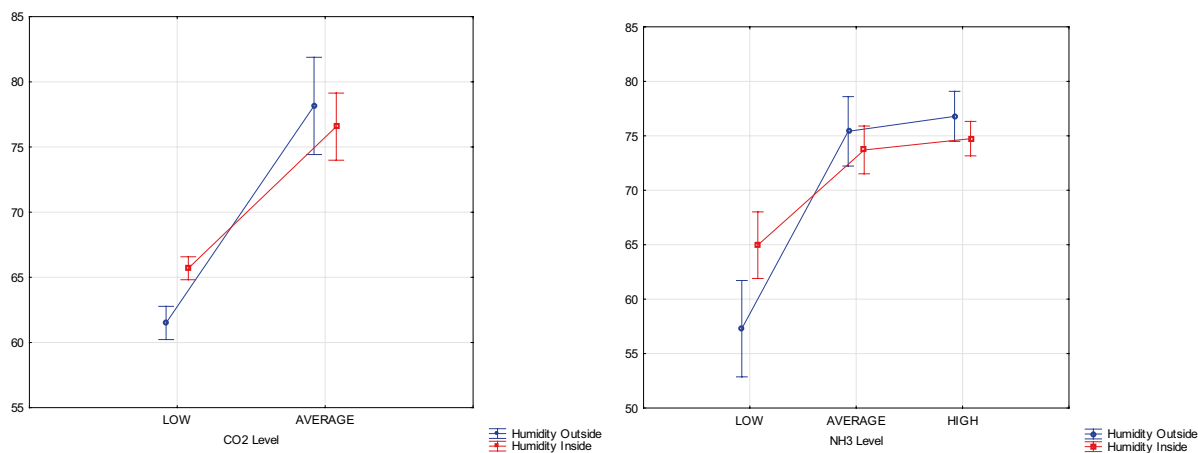
Fig. 2 The results of relative humidity outside and relative humidity inside comparison with the CO_2 and NH_3 levels. Source: own study

the significance level (p) was 0.01184 and the statistical empirical value $F_{(2, 846)} = 4.4595$. The case of temperature impact on the CO_2 emission level, inversely than the NH_3 emission level, delivers the correlation. The obtained results were the basis for the Duncan tests that determine the temperature values to homogeneous groups. The analysis showed that each of the tested temperatures is in a different homogeneous group, which makes significant differences in the temperature impact on the level of CO_2 emissions. The mean temperature for the low level of the CO_2 emission was 21.5 °C, for the average level was close to the 23.2 °C, but high emission was not known. The correlation of relative humidity outside and relative humidity inside with the NH_3 emissions from cattle houses was conducted. The estimated recommended levels of NH_3 emissions were also used. The results of relative humidity outside and humidity inside correlation with the CO_2 and NH_3 levels were presented in Fig. 2.

It was statistically confirmed that the relative humidity outside and relative humidity inside had an influence on the CO_2 and NH_3 emission levels in both cases. Similarly, in both statistical analyses, the significance value (p) was below a critical level, which means that the correlation exists. The empirical value of statistics $F_{(2, 845)}$ during the relative humidity outside and relative humidity inside comparison with the CO_2 was equal to 34.726, and the Wilks Lambs = 0.92405. In the case where the relative humidity outside and relative humidity inside were

correlated with NH_3, the empirical value of statistics $F_{(4, 1690)} = 17.507$ and the Wilks Lambs = 0.92201. The characteristics of homogeneous groups defining the effect of relative humidity outside and relative humidity inside comparison with the CO_2 and NH_3 levels were presented in Table 5.

According to Table 6, the increase of relative humidity outside and relative humidity inside caused the increase of CO_2 and NH_3 emission. Statistical analysis confirmed the need for reducing the relative humidity inside to limit the CO_2 and NH_3 emissions. Considering the whole scope of the conducted studies, it can be noticed that the best conditions for limiting CO_2 are to reduce temperature and humidity

Table 5 Characteristics of homogeneous groups defining the effect of relative humidity outside and relative humidity inside comparison with the CO_2 and NH_3 levels

Emission level	CO_2		NH_3	
	Mean of relative humidity outside	Mean of relative humidity inside	Mean of relative humidity outside	Mean of relative humidity inside
	%			
Low	60.9[a]	64.1[a]	58.5[a]	60.6[a]
Average	86.5[b]	78.9[b]	66.4[b]	68.8[b]
High	-	-	73.1[c]	73.4[c]

[a,b,c]Homogeneous groups

Source: own study

Table 6 Air exchange rates in cattle barns according to Polish standards

Summer	Winter
350–400 m$^3 \cdot$h^{-1} for dairy cows	90 m$^3 \cdot$h^{-1}
For cows with higher milk yield, it should be increased by 25%	Deep litter—increase by 50%

Source: own elaboration based on Collective work (2005)

outside and inside of livestock housing. Ammonia emission could be reduced by simultaneously decreasing air humidity and decreasing air temperature. In the case of NH$_3$ emission, reduction is necessary to increase the temperature and reduce the humidity inside the building.

Discussion

Results derived from our emission experiments were common to other authors (Walczak and Krawczyk) despite weather conditions. In particular, in non-litter cowsheds, higher NH$_3$ emissions were observed. A similar situation was described by Zhang who tested ammonia emissions from 11 types of cattle barns, with different floor and manure removing systems and the highest emission was in non-littered cattle barns (Zhang et al., 2005).

Similar results were obtained by a Polish researcher, which calculated ammonia emissions by using model (not measured) from dairy cattle for particular technologies ranging from 6.4 per year for deep litter up to 28.69 kg per year for a slurry system, but these results based only on simply assuming fixed rate of nitrogen losses from manure in livestock buildings (Pietrzak, 2006).

Mosquera et al. (2005) stated that from barns with deep litter, an average ammonia emission was at the level of 13.9 kg per cow and year. It is known from other research tests that ammonia emission from cattle barn with the solid floor was about 50% lower than emission from buildings with the slatted floor (Swierstra et al., 1995). In contrast, research conducted by Baldini shows higher emission factors in cubicles covered with straw (Baldini et al., 2016).

Also, differences of NH$_3$ emissions observed between tied and loose housing were observed by Poteko et al. (2019). A mechanical ventilation system

was used and ammonia concentration was measured 10 times per hour from exhaust air. In experiments, single data was as average value from measurements during summer season. In our conducted tests for this article, the single result was based on the average from every 5 min during a couple of chosen, representative days in the summer period.

Jungbluth et al. (2001) were conducting NH$_3$, CO$_2$ and CH$_4$ in respiratory chambers and in cattle barn for 50 cows with gravitational ventilation. In building, 27.8 to 50 g$\cdot$h^{-1} per LU of ammonia emission was obtained. According to results obtained by Koerkamp et al. (1998), ammonia emission from boxed barns was at wide level 987–2001 mg$\cdot$h^{-1}per animal.

There were ammonia emissions tested from beef and dairy cattle barns, and the following results are obtained by Demmers: from a system with slurry, 3.7 kg during 190 days of being inside livestock buildings for beef cattle, and 6 kg during 190 days of being inside livestock buildings for dairy cattle (both indicators based per 500 kg of live weight) (Demmers et al., 1998).

In our research, we obtained higher emissions from all object tested (with bedding and without bedding) compared to other authors' results.

Table 6 shows the recommended values of the air exchange rate in buildings for cattle in Poland. Only one of the cattle barns tested had ventilation rate below the recommended values.

According to Demmers et al. (1998), the annual NH$_3$ emission from litter-free barns was about two times higher than emission from barns with litter. A similar trend was obtained in our research, where the emission from the litter-free system in one of the barns was about 24 kg$\cdot$year$^{-1}\cdot$LU^{-1}and for the litter system 12.87 kg$\cdot$year$^{-1}\cdot$LU^{-1}.

Conclusions

Recently, livestock production significantly increased in Central Europe that involved the need of correction of emission factors. Generally, in Poland, it is utilized emission coefficient elaborated in Northern European countries (UK, DK and NL). In this study, first step was made to present Polish emission factor dedicated especially to summer season conditions.

Although the change of temperature and humidity was not huge, measured values allowed estimating the

levels of gas emission in order to carry out the statistical analysis. According to the study, the increase of relative humidity outside and relative humidity inside caused an increase of CO_2 and NH_3 emission. A completely different validity occurred in accordance to the measured temperature values, where the increase in temperature could cause the reduction of NH_3 emission. However, this validity was not confirmed by statistical analysis where the lack of temperature influence on the NH_3 emission level confirms the value significance level $p = 0.01184$. All other cases of statistical analysis have reached the significance value p below the critical level of 0.05. The main conclusion from the research is that ammonia emissions from cattle barns with slurry were higher than from cattle barn bedded with straw, but simultaneously in the night period, both emission levels were comparable.

Data availability   Due to confidentiality agreements, supporting data can only be made available to bona fide researchers subject to a non-disclosure agreement. Details of the data and how to request access are available from Kamil Roman at Warsaw University of Life Sciences WULS.

References

Baldini, C., Borgonovo, F., Gardoni, D., & Guarino, M. (2016). Comparison among NH_3 and GHGs emissive patterns from different housing solutions of dairy farms. *Atmospheric Environment, 141*, 60–66. https://doi.org/10.1016/j.atmosenv.2016.06.047

Bjerg, B., Norton, T., Banhazi, T., Zhang, G., Bartzanas, T., Liberati, P., Cascone, G., Lee, I., & Marucci, A. (2013a). Modelling of ammonia emissions from naturally ventilated livestock buildings. Part 1: Ammonia release modelling, *Biosystems engineering, 116*(3):232–245. https://doi.org/10.1016/j.biosystemseng.2013.08.001

Bjerg, B., Cascone, G., In-Bok, L., Bartzanas, T., Norton, T., Hong Se, W., Seo Il, H., Banhazi, T., Liberati, P., Marucci, A., & Zhang, G. (2013b). Modelling of ammonia emissions from naturally ventilated livestock buildings. Part 3: CFD modelling. *Biosystems engineering, 116*(3):259–275. https://doi.org/10.1016/j.biosystemseng.2013.06.012

Bougouin, A., Leytem, A., Dijkstra, J., Dungan, R. S., & Kebreab, E. (2016). Nutritional and environmental effects on ammonia emissions from dairy cattle housing: A meta-analysis. *Journal of Environmental Quality, 45*, 1123. https://doi.org/10.2134/jeq2015.07.0389

Collective work (Domasiewicz T., Głaszczka A., Mazur K., Wardal W., Rudnik K., Winnicki S., Eymontt A., Rasmussen J.B., Nielsen L.A.H., Pedersen J.,Frederiksen J., Brikkjaer K.O., Jepsen L., Morsing S.) Housing systems for cattle. Handbook (2005). IBMER, Warsaw, Poland and DAAS, Skejby Denmark, pp.172.

Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., Dentener, F., van Aardenne, J. A., Monni, S., Doering, U., Olivier, J. G. J., Pagliari, V., & Janssens-Maenhou, G. (2018). Gridded emissions of air pollutants for the period 1970-2012 within EDGAR v4.3.2 *Earth System Science Data Discussions*, https://doi.org/10.5194/essd-2018-31

Demmers, T. G. M., Burgess, L. R., Short, J. L., Phillips, V., Clark, J. A., & Wathes, C. M. (1998). First experiences with methods to measure ammonia emissions from naturally ventilated cattle buildings in the U.K. *Atmospheric Environment, 32*(3): 285–293.

Dore, C. J., Jones, B. M. R., Scholtens, R. H., & In't Veld, Burgess, J. R. L., & Phillips, V. R. (2004). Measuring ammonia emission rates from livestock buildings and manure stores - part 2: Comparative demonstrations of three methods on the farm. *Atmospheric Environment, 38*(19), 3017–3024

Edouard, N., Mosquera, J., & van Dooren, H. J. C. (2016). Comparison of CO_2 and SF6-based tracer gas methods for the estimation of ventilation rates in a naturally ventilated dairy barn. *Biosystems Engineering, 149*, 11–23. https://doi.org/10.1016/j.biosystemseng.2016.06.001

EUROSTAT. (2020). Ammonia emissions from agriculture (EEA) https://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=sdg_02_60&language=en available on-line 5.06.2020

Ferm, M., Marcinkowski, T., Kieronczyk, M., & Pietrzak, S. (2005). Measurements of ammonia emissions from manure storing and spreading stages in Polish commercial farms. *Atmospheric Environment., 39*(37), 7106–7113

Gridnev, P. I., Gridneva, T., Spotaru, J., Romaniuk, W. (2014). Влияние технологий производства молока на ущерб окружающей среды [The impact of technology on the milk production of environmental damage] Ed. W. Romaniuk. In: *Проблемы интенсификации животноводства с учетом охраны окружающей среды и производства альтернативных источников энергии, в том числе биогаза* [Problems of animal production intensification with regard to environment protection and alternative energy production, including biogas]. Warszawa-Falenty. ISBN 978–83–62416–75–2, 84–94.

Herbut, P., & Angrecka, S. (2014). Ammonia concentrations in a free-stall dairy barn. *Annals Animal Science, 14*(1), 153–166. https://doi.org/10.2478/aoas-2013-0065.

Jungbluth, T., Brose, G., & Hartung, E. (2001). Greenhouse gas emissions from animal houses and manure stores. *Nutrient Cycling in Agroecosystems, 60*, 133–145

Karłowski, J., Myczko, R., Kołodziejczyk, T., & Kuczyński, T. (2008). Współczynniki emisji amoniaku i gazów cieplarnianych z obór z wentylacją mechaniczną. *Problemy Inżynierii Rolniczej, 1*(59):151–158 https://www.itp.edu.pl/wydawnictwo/pir/zeszyt_59_2008/karlowski_wspolczynniki_p.pdf

Kiwan, A., Berg, W., Fiedler, M., Ammon, Ch., Gläser, M., Müller, H. J., & Brunsch, R. (2012). Air exchange rate measurements in naturally ventilated dairy buildings using the tracer gas decay method with 85Kr, compared to CO_2 mass balance and discharge coefficient methods. *Biosystems Engineering, 116*(3), 286–296. https://doi.org/10.1016/j.biosystemseng.2012.11.011

Koerkamp, G., Metz, J. H. M., Uenk, G. H., Philips, V. R., Holden, M. R., Sneath, R. W., & Short, J. L. (1998). Concentration and emissions of ammonia in livestock buildings in Northern Europe. *Journal of Agricultural Engineering Research, 70*(1), 79–95

Krawczyk, W., & Walczak, J. (2010). Potencjał biogenny obornika jako źródło emisji amoniaku i zagrożenia środowiska (Biogenic potential of manure as a source of ammonia emission and environmental threat). *Roczniki Naukowe Zootechniki, 37*(2):187–193. https://rnz.izoo.krakow.pl/files/RNZ_2010_37_2_art12.pdf

Marcinkowski, T. (2010). Emisja gazowych związków azotu z rolnictwa [The emission of gaseous nitrogen compounds from agriculture]. Woda – Środowisko – Obszary Wiejskie, 1/3(31):175–189.

Mohn, J., Zeyer, K., Keck, M., Keller, M., Zähner, M., Poteko, J., Emmenegger, L., & Schrade, S. (2018). A dual tracer ratio method for comparative emission measurements in an experimental dairy housing. *Atmospheric Environment* 179, 12–22. https://doi.org/10.1016/j.atmosenv.2018.01.057

Mosquera, J., Monteny, G. J., & Erisman, J. W. (2005). Overview and assessment of techniques to measure ammonia emissions from animal houses: the case of the Netherlands. *Environmental Pollution, 135*(3), 381–388. https://doi.org/10.1016/j.envpol.2004.11.011

Müller, H. J., Möller, B., Gläser, M., & Cespiva, M. (2007) *Determination of ammonia emission from naturally ventilated animal houses*. In: Monteny G. J., Hartung E. (Ed.), Ammonia emissions from agriculture. Wageningen. Germany. Potsdam. Praha. Czech Republic:359–360. https://www.scopus.com/record/display.uri?eid=2-s2.0-84885062785&origin=inward&txGid=809ac40fb6a9824ae8f7cbdcca0632bf

Nosek, Š., Kluková, Z., Jakubcová, M., Yi, Q., Janke, D., Demeyer, P., Jaňour, Z. (2020). The impact of atmospheric boundary layer, opening configuration and presence of animals on the ventilation of a cattle barn. *Journal of Wind Engineering and Industrial Aerodynamics,* 201:104185. https://doi.org/10.1016/j.jweia.2020.104185

Philippe, F. X., & Nicks, B. (2015). Review of greenhouse gas emissions from pig houses: Production of carbon dioxide, methane and nitrous oxide by animals and manure. *Agriculture, Ecosystems & Environment, 199*(1), 10–25. https://doi.org/10.1016/j.agee.2014.08.015

Pietrzak, S. (2006). Metoda inwentaryzacji emisji amoniaku ze źródeł rolniczych w Polsce i jej praktyczne zastosowanie. Woda - Środowisko-Obszary Wiejskie 1(16):319–334 https://www.itp.edu.pl/wydawnictwo/woda/zeszyt_16_2006/artykuly/Pietrzak1.pdf

Poteko, J., Zähner, M., & Schrade, S. (2019). Effects of housing system, floor type and temperature on ammonia and methane emissions from dairy farming: A meta-analysis. *Biosystems Engineering, 182*, 16–28. https://doi.org/10.1016/j.biosystemseng.2019.03.012

Roman, M., Roman, K., & Roman, M. (2019). Methods of estimating particulates emission in agriculture exemplified by animal husbandry. [in:]. *Proceedings of the International Scientific Conference Hradec Economic Days. Published University of Hradec Kralove, Faculty of Informatics and Management, Hradec Kralove. 9*(2), 260–268. https://digilib.uhk.cz/bitstream/handle/20.500.12603/159/ROMAN,%20ROMAN,%20ROMAN.pdf?sequence=1

Sanchis, E., Calvet, S., del Prado, A., & Estellés, F. (2019). A meta-analysis of environmental factor effects on ammonia emissions from dairy cattle houses. *Biosystems Engineering, 178*, 176–183. https://doi.org/10.1016/j.biosystemseng.2018.11.017

Swierstra, M., Smits, C. J., & Kroodsma, W. (1995). Ammonia emission from cubicle houses for cattle with slatted and solid floors. *Journal of Agricultural Engineering Research, 62*(2), 127–132. https://doi.org/10.1006/jaer.1995.1071

Yi, Q., Wang, X., Zhang, G., Li, H., Janke, D., & Amon, T. (2019a). Assessing effects of wind speed and wind direction on discharge coefficient of sidewall opening in a dairy building model – A numerical study. *Computers and Electronics in Agriculture, 162*, 235–245. https://doi.org/10.1016/j.compag.2019.04.016

Yi, Q., Li, H., Wang, X., Zong, Ch., & Zhang, G. (2019b). Numerical investigation on the effects of building configuration on discharge coefficient for a cross-ventilated dairy building model. *Biosystems Engineering, 182*, 107–122. https://doi.org/10.1016/j.biosystemseng.2019.04.003

Zhang, G., Strøm, J. S., Li, B., Rom, H. B., Morsing, S., Dahl, P., & Wang, C. (2005). Emission of ammonia and other contaminant gases from naturally ventilated dairy cattle buildings. *Biosystems Engineering, 92*(3), 355–364. https://doi.org/10.1016/j.biosystemseng.2005.08.002