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 CO₂ 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·h⁻¹·LU⁻¹ in well-ventilated cattle barn with the largest herd size.

Keywords Emissions · Ammonia · Natural ventilation · Air exchange

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 |
| CH₄ losses (eq.CO₂), t | 344.5 | 347.8 | 834.4 | 819.9 |
| Emission CH₄∙kg∙cow∙year⁻¹ | 4.05 | 4.16 | 4.65 | 4.84 |
| N₂O losses (eq. CO₂), 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 (Bouguin 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. Bouguin described negative impact of milk production on NH₃ emission that milk yield had on NH₃ emissions (Bouguin et al., 2016).

Demmers indicates that the CO₂ balance method demands not only the presence of animals inside the building but also detailed knowledge about CO₂ 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.
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 CO₂, SF6 or cryptone 85 as tracer gases (Müller et al., 2007; Kiwan et al., 2012). Édouard et al. (2016) used tracer gas method as well as moisture balance method. Indicators of CO₂ emissions by livestock animals and water vapor are not constant and depend on the animals, age and diet. In our study, the CO₂ 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 $W_{CO2} = 220 \text{ g·h}^{-1}·\text{LU}^{-1}$ 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):

$$E = V \cdot S$$  (1)

where:

- $E$—ammonia emission from building [g·h⁻¹·LU⁻¹],
- $V$—air exchange rate in building [m³·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].

### 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       |
| CH₄            | 108.4          | 112.91           | 123.53            | 126.32              | 119.2          | x       |
| N₂O            | 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  |
| CH₄            | 56.3           | 57.4             | 79.32             | 84.27               | 66.73          | 67.58   |
| N₂O            | 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   |
| CH₄            | x              | x                | 21.2              | 24.47               | x              | 19.6    |
| N₂O            | x              | x                | 0.002             | 0.004               | x              | 0.006   |

Source: own elaboration based on Krawczyk and Walczak (2010)
The ventilation rate was calculated using the carbon dioxide balance method from the equation:

\[ V = \frac{W_{\text{CO}_2}}{C_{\text{inside}} - C_{\text{outside}}} \text{ m}^3 \cdot \text{h}^{-1} \]

(2)

where:

- \( V \) — air exchange rate in building [m\(^3\)·h\(^{-1}\)·LU\(^{-1}\)],
- \( W_{\text{CO}_2} \) — metabolic emission of carbon dioxide by one LU [g·h\(^{-1}\)·LU\(^{-1}\)],
- \( C_{\text{inside}} \) — average CO\(_2\) concentration inside cattle barn—average from measurement points measured in particular time [ppm, converted into g·m\(^{-3}\)],
- \( C_{\text{outside}} \) — average CO\(_2\) concentration in air inflowing into the building [ppm, converted into g·m\(^{-3}\)].

Finally, ammonia emission was equal:

\[ E = \frac{W_{\text{CO}_2}}{C_{\text{inside}} - C_{\text{outside}}} \cdot S \]

(3)

where:

- \( E \) — ammonia emission from building [g·h\(^{-1}\)·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·h\(^{-1}\)·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
1.47 (g·h⁻¹·LU⁻¹) was observed in a cattle barn with the lowest cubage.

According to the above-presented table, the values of NH₃ and CO₂ emission levels were estimated. The established high, average and low levels of gas emissions were created, as multiple values of 7 ppm for NH₃ and 1000 ppm for CO₂. Created levels were dependent on the recommended limits of NH₃ that equal 20 ppm and CO₂ 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 CO₂ and NH₃ levels were presented in Fig. 1.

During the statistical analysis, the expected marginal mean of temperature influence to CO₂ and NH₃ emission density was specified. In the case of temperature impact on the CO₂ 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 NH₃ emission level delivers that

**Table 4** Gaseous emissions from housing systems of objects tested (kg·year⁻¹·LU⁻¹)

| No. of cow-shed | Statistical value | Temperature inside [°C] | Relative humidity outside [%] | Relative humidity inside [%] | Air exchange rate (V) [m³·h⁻¹·LU⁻¹] | NH₃ emission* [ppm] | NH₃ emission* [g·h⁻¹·LU⁻¹] | CO₂ emission [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°C
- Optimal 70% RH max. 80% RH

*Day/night, 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 \( \text{CO}_2 \) emission level, inversely than the \( \text{NH}_3 \) 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 \( \text{CO}_2 \) emissions. The mean temperature for the low level of the \( \text{CO}_2 \) 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 \( \text{NH}_3 \) emissions from cattle houses was conducted. The estimated recommended levels of \( \text{NH}_3 \) emissions were also used. The results of relative humidity outside and humidity inside correlation with the \( \text{CO}_2 \) and \( \text{NH}_3 \) levels were presented in Fig. 2.

It was statistically confirmed that the relative humidity outside and relative humidity inside had an influence on the \( \text{CO}_2 \) and \( \text{NH}_3 \) 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 \( \text{CO}_2 \) 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 \( \text{NH}_3 \), 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 \( \text{CO}_2 \) and \( \text{NH}_3 \) levels were presented in Table 5.

According to Table 6, the increase of relative humidity outside and relative humidity inside caused the increase of \( \text{CO}_2 \) and \( \text{NH}_3 \) emission. Statistical analysis confirmed the need for reducing the relative humidity inside to limit the \( \text{CO}_2 \) and \( \text{NH}_3 \) emissions. Considering the whole scope of the conducted studies, it can be noticed that the best conditions for limiting \( \text{CO}_2 \) are to reduce temperature and humidity

![Fig. 2](image-url) The results of relative humidity outside and relative humidity inside comparison with the \( \text{CO}_2 \) and \( \text{NH}_3 \) levels. Source: own study

| Emission level | \( \text{CO}_2 \) Mean of relative humidity outside | \( \text{NH}_3 \) 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
outside and inside of livestock housing. Ammonia emission could be reduced by simultaneously decreasing air humidity and decreasing air temperature. In the case of NH₃ 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 NH₃ 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 NH₃ 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 NH₃, CO₂ and CH₄ in respiratory chambers and in cattle barn for 50 cows with gravitational ventilation. In building, 27.8 to 50 g·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·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 NH₃ 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·year⁻¹·LU⁻¹ and for the litter system 12.87 kg·year⁻¹·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 CO₂ and NH₃ emission. A completely different validity occurred in accordance to 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.

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