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EFFECT OF SEASON ON GASES EMISSIONS FROM FREE-STALL BARNS FOR DAIRY COWS

Summary

Livestock buildings are an important source of ammonia, methane and nitrous oxide. In naturally ventilated buildings for dairy cattle interaction of weather conditions and microclimate parameters in livestock buildings have an impact on the emission of ammonia and greenhouse gases. The aim of the study was to determine the effect of the seasons on the emission of greenhouse gases (CH_4, N_2O) and ammonia from barns for dairy cows. The study was conducted in 6 free-stall barns located in the Wielkopolska Voivodship, during: spring, summer and fall. The median of CH_4 emission factor was 14.8±2.3 g·h^{-1}·cow^{-1} in spring, 16.9±3.2 g·h^{-1}·cow^{-1} in summer, 17.3±2.1 g·h^{-1}·cow^{-} in fall. For N_2O and NH_3 values were 0.085±0.067 g·h^{-1}·cow^{-1} in spring, 0.120±0.060 g·h^{-1}·cow^{-1} in summer, 0.062±0.049 g·h^{-1}·cow^{-1} in fall and 1.13±0.34 g·h^{-1}·cow^{-1} in spring, 1.17±0.45 g·h $^{-1}$·cow^{-1} in summer, 0.77±0.37 g·h^{-1}·cow^{-1} in fall, respectively. The analysis for all barns showed statistically significant differences in the values of emission factors between seasons ($\alpha = 0.05$). For NH_3 and CH_4 they were not observed only between spring and summer, and for N_2O between spring and fall ($\alpha = 0.05$).

***Key words**: gases emission, greenhouse gases, ammonia, free-stall barn, dairy cows*

WPŁYW PORY ROKU NA EMISJE GAZÓW Z OBÓR WOLNOSTANOWISKOWYCH DLA KRÓW MLECZNYCH

Streszczenie

Budynki inwentarskie są głównym źródłem amoniaku, metanu i podtlenku azotu. W naturalnie wentylowanych obiektach dla bydła mlecznego wzajemne oddziaływanie warunków pogodowych oraz parametrów mikroklimatu wewnątrz budynków inwentarskich kształtuje emisję amoniaku i gazów cieplarnianych do otaczającego je środowiska. Celem pracy było określenie wpływu pór roku na emisję gazów cieplarnianych (CH_4, N_2O) i amoniaku z kilku obór dla krów mlecznych. Badania przeprowadzono w 6 oborach wolnostanowiskowych zlokalizowanych w województwie wielkopolskim, w trzech seriach: wiosennej, letniej oraz jesiennej. Mediana wskaźnika emisji CH_4 wynosiła 14.8±2.3 g·h^{-1}·szt.$^{-1}$ wiosną, 16.9±3.2 g·h^{-1}·szt.$^{-1}$ latem i 17.3±2.1 g·h^{-1}·szt.$^{-1}$ jesienią. Dla N_2O i NH_3 wartości te wynosiły odpowiednio 0.085±0.067 g·h^{-1}·szt.$^{-1}$ wiosną, 0.120±0.060 g·h^{-1}·szt.$^{-1}$ latem i 0.062±0.049 g·h^{-1}·szt.$^{-1}$ jesienią oraz 1.13±0.34 g·h^{-1}·szt.$^{-1}$ wiosną, 1.17±0.45 g·h^{-1}·szt.$^{-1}$ latem i 0.77±0.37 g·h^{-1}·szt.$^{-1}$ jesienią. Ogólna analiza dla wszystkich obór wykazała statystycznie istotne różnice w wartościach wskaźników emisji między porami roku (α=0.05). W przypadku NH_3 i CH_4 nie zaobserwowano tych różnic jedynie dla wiosny i lata, a w przypadku N_2O dla wiosny i jesieni (α=0.05).

***Słowa kluczowe**: emisja gazów, gazy cieplarniane, amoniak, obora wolnostanowiskowa, krowy mleczne*

1. Introduction

Livestock buildings are an important source of ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O). Ammonia causes eutrophication and acidification of the soil, while the CH_4 and N_2O are greenhouse gases that contribute to global warming [9, 10, 23]. In Poland, the share of agriculture in national gases emission was 98% for NH_3, 77% for N_2O and 32% for CH_4 in 2013. The share of dairy cattle in emissions from livestock production was 30% for NH_3, 58% for CH_4 [6, 7] and 21% for N_2O.

In mild climates, buildings for dairy cows are usually naturally ventilated. Such objects have an open-frame construction with half-open side walls and open roof ridge. The air circulation is caused by physical phenomena: the difference in outside and inside temperatures and the force of wind, what decreases the operating costs of the building [8, 18]. On the other hand, the weather conditions strongly impact the microclimate inside the naturally ventilated barns [16, 19]. Changes of microclimate parameters affect the activity, behavior and performance of cows [12].

The interaction of weather conditions and microclimate parameters inside livestock buildings determines the emission of ammonia and greenhouse gases into environment. The key climatic factors influencing the gas emissions are outside temperature, relative humidity and wind force and direction [22].The studies carried out in many countries by Sommer et al. [20], Pereira et al. [13], Feidler and Müller [4], Wu et al. [22], Schrade et al. [17], Rong et al. [14] and VanderZaag et al. [21] confirm the effect of weather conditions (temperature, relative humidity and wind force) on the emission of greenhouse gases and ammonia from buildings for dairy cows. Analysis of published Polish works showed a lack of research on the relationship between the season and the emission of harmful gases from buildings for dairy cows.

The aim of the study was to determine the effect of the seasons on the emission of greenhouse gases (CH_4, N_2O) and ammonia from several barns for dairy cows.

2. Material and Methods

Studied barns

The study was conducted in six free-stall barns located in the Wielkopolska voivodship. All of the barns were naturally ventilated, and during hot days the natural ventilation was supported by mechanical fans. Buildings differed in number of animals, type of the resting area, manure removal system and the milk yield:

Barn 1: collective shallow litter, 180 cows, 6874 $dm^3 \cdot cow^{1} \cdot year^{-1}$,
Barn 2: non-littered stalls with slatted floor, 70 cows, 9890 $dm^3 \cdot cow^{1} \cdot year^{-1}$,
Barn 3: collective deep litter, 240 cows, 8482 $dm^3 \cdot cow^{1} \cdot year^{-1}$,
Barn 4: littered stalls with solid floor, 240 cows, 8637 $dm^3 \cdot cow^{1} \cdot year^{-1}$,
Barn 5: littered stalls with solid floor, 240 cows, 10498 $dm^3 \cdot cow^{1} \cdot year^{-1}$,
Barn 6: non-littered stalls with slatted floor, 160 cows, 8987 $dm^3 \cdot cow^{1} \cdot year^{-1}$.

Temperature, relative humidity and gas concentration

The study was carried out in three series: spring (from 24 April to 24 May), summer (from 4 July to 23 July) and fall (from 5 November to 3 December). During winter (freezing temperatures) studies were not conducted because of the technical limitations of measuring equipment. During one series in each tested barn there were made 24 measurements of temperature, relative humidity and gas concentrations.

The temperature and relative humidity of the air inside and outside the building were measured using the logger Testo 175 H2, with an accuracy of 0.5°C and 3%, respectively. Measurements of the gases concentration (CH_4, N_2O and NH_3) on the outside and inside of the building were made by photoacoustic spectrometer Multi Gas Monitor Innova 1312. Accuracy was 0.06 $mg \cdot m^{-3}$ for N_2O, 0.29 $mg \cdot m^{-3}$ for CH_4 and 0.15 $mg \cdot m^{-3}$ for NH_3. The choice of the localization of measurement point for gases concentration inside studied objects was preceded by measurements at several points in each of the barns. These studies confirmed the uniform mixing of the air in all volume of barns. Therefore the daily measurements were made at one point, located in the center of the building at a half of the total barn height. The outside measurement point of gas concentrations was in a distance of at least 10 meters from the windward side of the building, at the height of inlets in the side walls.

Ventilation rate and gases emission

The ventilation rate was determined according to the CIGR methodology [3]. This method is based on a comparison of the concentration of carbon dioxide inside and outside the building. The difference between the CO_2 concentration is related to the rate of carbon dioxide production and the efficiency of ventilation [2, 15]. The ventilation rate VR ($m^3 \cdot h^{-1}$) was calculated from equations (1-3):

$$VR = \frac{n \cdot P_{CO_2}}{C_{inCO_2} - C_{outCO_2}}, \qquad (1)$$

where:
n – the number of cows,
P_{CO2} – the amount of CO_2 emitted by one cow ($mg \cdot h^{-1} \cdot cow^{-1}$),
C_{inCO2} – CO_2 concentration inside the building ($mg \cdot m^{-3}$),
C_{outCO2} – CO_2 concentration outside the building ($mg \cdot m^{-3}$).

$$P_{co_2} = 299 \cdot q_t \cdot (4 \cdot 10^{-5} \cdot (20 - t_{in})^3 + 1) \qquad (2)$$

where:
q_t – the total heat produced by cows (W),
t_{in} – the inside temperature (°C).

$$q_t = 5.6 \cdot m^{0.75} + 1.6 \cdot 10^{-5} \cdot p^3 + 22 \cdot y \qquad (3)$$

where:
m - cow's mass (kg),
p – number of days after insemination (day),
y – milk yield ($kg \cdot day^{-1}$).

Source: Authors' photo/ Źródło: zdjęcie autorów

Fig. 1. Measurement apparatus in barn 3
Rys. 1. Stanowisko pomiarowe w oborze 3

The values p, m, and y, which are necessary to calculate the total heat produced by animals, were collected from the database of electronic herd management systems

The greenhouse gases and ammonia emissions E_g ($g \cdot h^{-1}$) from studied barns were calculated according to the equation (4):

$$E_g = VR \cdot (C_{in} - C_{out}) \cdot 10^{-3} \qquad (4)$$

where:
C_{in} – the gas concentration inside the building ($mg \cdot m^{-3}$),
C_{out} – the gas concentration outside the building ($mg \cdot m^{-3}$).

The gas emission factors were related to one cow. The average mass of one cow was determined based on the culling cows documentation. The mean mass was 650 kg in all barns.

3. Results and discussion

Weather conditions directly impact emissions of air pollutants, especially from naturally ventilated livestock buildings. They affect microclimate parameters in the barn, such as air flow, temperature and relative humidity, which determine the concentration of pollutants and ventilation rate. Weather and microclimate data (median and quartile deviation), monitored during study, are shown in Table 1.

The measurement results of selected weather and microclimate parameters were statistically analyzed. The Kruskal-Wallis test and multiple comparisons of mean ranks for all groups confirmed the presence of the differences between the measured parameters in individual seasons in all barns ($p \leq 0.05$).

The medians of daily gas concentrations inside and outside the buildings and quartile deviation are presented in Tables 2 and 3.

Based on the measurement results of greenhouse gases and ammonia concentrations and ventilation rates the emissions of gases from the studied barns were calculated using equation (4). The gas emission factors (the emissions expressed per one cow) are shown in Table 4.

Table 1. Daily air temperature, relative humidity and ventilation rate
Tab. 1. Dobowa temperatura i wilgotność względna powietrza oraz wymiana powietrza

Season			Spring	Summer	Fall
Temperature (ºC)	Barn 1	Outside	16.1±4.3	21.0±2.6	9.3±0.6
		Inside	19.0±2.6	22.1±2.1	12.0±0.6
	Barn 2	Outside	15.0±3.7	24.3±3.4	6.9±0.6
		Inside	16.5±3.8	24.3±3.4	8.4±0.5
	Barn 3	Outside	13.9±2.1	21.1±2.0	6.0±0.8
		Inside	14.0±1.9	21.3±1.5	7.0±0.6
	Barn 4	Outside	17.1±3.0	22.6±2.0	9.4±0.3
		Inside	18.6±1.1	22.6±2.7	13.2±0.4
	Barn 5	Outside	15.3±5.4	21.0±2.6	1.4±1.1
		Inside	16.7±3.1	23.3±2.4	2.0±1.2
	Barn 6	Outside	14.2±3.5	17.5±1.7	9.3±0.5
		Inside	16.9±1.5	18.5±1.0	10.2±0.5
Relative humidity (%)	Barn 1	Outside	69.2±6.3	67.1±7.7	90.2±4.0
		Inside	76.6±7.5	68.6±3.7	90.8±4.1
	Barn 2	Outside	54.6±4.7	82.4±5.6	89.1±2.4
		Inside	55.7±5.2	76.6±4.7	90.0±2.6
	Barn 3	Outside	60.5±7.0	86.1±5.6	86.9±2.8
		Inside	71.9±5.7	87.7±5.1	86.6±2.9
	Barn 4	Outside	41.9±5.3	62.8±9.7	81.2±2.6
		Inside	48.0±6.6	70.0±5.1	82.8±2.9
	Barn 5	Outside	57.4±7.7	76.7±3.2	87.4±1.6
		Inside	59.5±4.4	83.1±4.6	90.5±3.2
	Barn 6	Outside	61.4±6.8	73.6±6.3	91.9±3.9
		Inside	63.2±6.8	79.5±9.2	94.6±2.4
Ventilation rate ($m^3 \cdot h^{-1} \cdot cow^{-1}$)	Barn 1		231±56	216±38	210±44
	Barn 2		703±247	693±114	345±40
	Barn 3		1672±730	674±156	663±163
	Barn 4		2314±836	1667±498	1539±529
	Barn 5		1486±420	1702±602	1148±224
	Barn 6		695±84	1976±336	779±140

Source: own work / Źródło: opracowanie własne

Table 2. Daily concentration of greenhouse gases
Tab. 2. Dobowe stężenia gazów cieplarnianych

Season			Spring	Summer	Fall
CH_4 concentration ($mg \cdot m^{-3}$)	Barn 1	Outside	3.30±0.20	8.74±0.48	1.32±0.65
		Inside	42.12±13.74	45.24±9.14	42.64±9.88
	Barn 2	Outside	7.51±0.52	13.76±0.43	1.25±0.33
		Inside	30.45±7.08	35.08±4.72	52.99±5.94
	Barn 3	Outside	2.73±0.32	11.44±0.14	0.83±0.21
		Inside	11.13±2.40	29.38±5.23	36.02±6.97
	Barn 4	Outside	2.99±0.21	7.31±0,33	3.93±0.83
		Inside	10.45±2.61	17.77±4.58	15.40±3.44
	Barn 5	Outside	4.69±0.17	10.32±0.64	0.47±0.03
		Inside	14.71±4.09	18.95±4.93	16.35±4.70
	Barn 6	Outside	3.46±0.06	6.12±0.47	0.80±0.29
		Inside	22.15±2.13	15.66±1.87	21.70±4.75
N_2O concentration ($mg \cdot m^{-3}$)	Barn 1	Outside	0.78±0.03	0.44±0.03	0.81±0.02
		Inside	0.86±0.07	0.55±0.06	0.95±0.05
	Barn 2	Outside	0.44±0.04	0.44±0.03	0.80±0.03
		Inside	0.62±0.05	0.71±0.06	1.04±0.03
	Barn 3	Outside	0.76±0.05	0.45±0.03	0.81±0.01
		Inside	0.81±0.03	0.68±0.10	0.93±0.03
	Barn 4	Outside	0.52±0.01	0.51±0.03	0.75±0.02
		Inside	0.57±0.02	0.60±0.04	0.85±0.04
	Barn 5	Outside	0.50±0.02	0.38±0.02	0.98±0.02
		Inside	0.63±0.03	0.45±0.03	1.02±0.03
	Barn 6	Outside	0.75±0.03	0.59±0.04	0.81±0.05
		Inside	0.79±0.03	0.66±0.03	0.88±0.04

Source: own work / Źródło: opracowanie własne

Table 3. Daily concentration of ammonia
Tab. 3. Dobowe stężenia amoniaku

Season			Spring	Summer	Fall
NH_3 concentration $(mg\cdot m^{-3})$	Barn 1	Outside	0.41±0.04	0.83±0.04	0.17±0.05
		Inside	5.60±1.43	2.99±0.60	1.63±0.28
	Barn 2	Outside	0.69±0.14	0.86±0.09	0.64±0.15
		Inside	2.29±0.61	3.08±0.85	2.76±0.35
	Barn 3	Outside	0.47±0.15	0.67±0.05	0.46±0.05
		Inside	0.84±0.08	2.49±0.25	1.31±0.18
	Barn 4	Outside	0.38±0.06	0.65±0.05	0.38±0.05
		Inside	0.71±0.18	1.18±0.15	0.93±0.08
	Barn 5	Outside	0.56±0.09	0.69±0.05	0.06±0.04
		Inside	1.56±0.24	2.13±0.39	1.04±0.17
	Barn 6	Outside	0.42±0.05	0.52±0.05	0.37±0.06
		Inside	2.19±0.32	0.96±0.20	1.05±0.27

Source: own work / Źródło: opracowanie własne

Table 4. Emission factors of greenhouse gases and ammonia
Tab. 4. Wskaźniki emisji gazów cieplarnianych i amoniaku

Season		Spring	Summer	Fall
CH_4 emission factor $(g\cdot h^{-1}\cdot cow^{-1})$	Barn 1	8.63±0.93	8.14±0.60	8.38±0.39
	Barn 2	16.29±1.25	14.75±0.56	18.15±2.45
	Barn 3	15.53±1.44	11.25±0.72	21.92±2.37
	Barn 4	18.21±1.44	18.24±2.99	19.65±0.54
	Barn 5	15.38±1.63	13.37±0.25	18.26±2.86
	Barn 6	13.09±0.55	19.36±0.28	17.00±0.67
N_2O emission factor $(g\cdot h^{-1}\cdot cow^{-1})$	Barn 1	0.013±0.008	0.028±0.015	0.024±0.011
	Barn 2	0.128±0.087	0.156±0.057	0.092±0.012
	Barn 3	0.081±0.039	0.183±0.038	0.081±0.025
	Barn 4	0.085±0.040	0.137±0.082	0.169±0.063
	Barn 5	0.205±0.088	0.129±0.064	0.040±0.024
	Barn 6	0.029±0.012	0.093±0.064	0.041±0.018
NH_3 emission factor $(g\cdot h^{-1}\cdot cow^{-1})$	Barn 1	1.14±0.23	0.43±0.14	0.29±0.10
	Barn 2	0.98±0.20	1.62±0.58	0.67±0.21
	Barn 3	0.62±0.28	1.41±0.38	0.53±0.09
	Barn 4	0.78±0.22	0.92±0.21	0.82±0.42
	Barn 5	1.42±0.27	1.99±0.53	1.05±0.49
	Barn 6	1.21±0.29	0.90±0.49	0.63±0.16

Source: own work / Źródło: opracowanie własne

Table 5. The result of multiple comparisons of mean ranks for all groups (differences in the gas emission factors between seasons)
Tab. 5. Wyniki wielokrotnych porównań średnich rang (różnice w wartościach współczynników emisji gazów między porami roku)

Barn	CH_4			N_2O			NH_3		
	Spring Summer	Summer Fall	Fall Spring	Spring Summer	Summer Fall	Fall Spring	Spring Summer	Summer Fall	Fall Spring
1	1.51^{NS}	0.95^{NS}	0.56^{NS}	3.27^{*}	0.56^{NS}	2.71^{*}	4.41^{*}	2.71^{*}	7.12^{*}
2	1.99^{NS}	4.78^{*}	2.79^{*}	1.72^{NS}	3.79^{*}	2.07^{NS}	3.12^{*}	5.05^{*}	1.92^{NS}
3	3.76^{*}	7.60^{*}	3.84^{*}	5.15^{*}	5.05^{*}	0.10^{NS}	4.47^{*}	5.88^{*}	1.41^{NS}
4	0.32^{NS}	1.50^{NS}	1.17^{NS}	2.90^{*}	0.66^{NS}	3.56^{*}	1.88^{NS}	0.54^{NS}	1.35^{NS}
5	2.50^{*}	4.75^{*}	2.28^{NS}	2.48^{*}	3.53^{*}	6.01^{*}	2.32^{NS}	3.92^{*}	1.60^{NS}
6	6.52^{*}	1.75^{NS}	4.77^{*}	4.19^{*}	1.98^{NS}	2.21^{NS}	2.66^{*}	2.39^{NS}	5.04^{*}

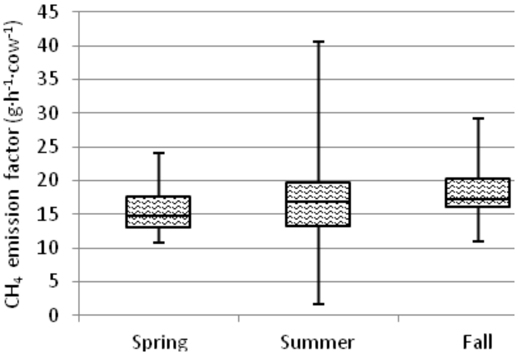
[*] – statistically significant difference ($p \le 0,05$)
[NS] – statistically insignificant difference

Source: own work / Źródło: opracowanie własne

The analysis of the effect of the seasons (temperature and humidity conditions) on the emission of studied gases does not allow to formulate the clear conclusions. The differences in values of daily emission factors do not occur between the same seasons in each studied barns. It may suggest that apart weather parameters, also other factors like: the type of the building, housing system and manure removal system may affect the gases emission. The conclusions of the study are not always consistent with the results of published studies. VanderZaag et al. [21] conducted the research of CH_4 emissions in free-stall dairy barn with sand litter. They showed differences between the fall and spring. The emission factors were lower in fall (10.4 $g\cdot h^{-1}\cdot cow^{-1}$), and higher in spring (28.4 $g\cdot h^{-1}\cdot cow^{-1}$). In this study, the methane emission factors were higher in fall than in spring. Mosquera et al. [11] during the measurements in the deep litter barn calculated gas emission factors for November and January. The CH_4 emission factor in November (37.5

g·h^{-1}·cow^{-1}) was higher than in January (29.1 g·h^{-1}·cow^{-1}). For NH_3 emission factors in these months were similar and amounted to 1.4 g·h^{-1}·cow^{-1} and 1.3 g·h^{-1}·cow^{-1}, respectively. Bluteau et al. [1] studied the emissions of NH_3 from the free-stall barn with sawdust bedding. Their results do not confirm the differences in the values of emission of NH_3 between spring, summer and fall. Joo et al. [5] analyzed the emissions of N_2O and CH_4 from two free-stall non litter barns and also found no differences in the values of emission factors between seasons.

To conduct an analysis of the effect of the seasons on the emission of greenhouse gases and ammonia for all barns together, the emission factors were grouped according to the season. The distribution of emission factors is shown on Figures 2-4. The bottom and top of box plots indicate the first quartile (Q_1) and third quartile (Q_3), respectively. The lines dividing the boxes show the median and the whiskers indicate the minimum and maximum values.



Source: own work / Źródło: opracowanie własne

Fig. 2. Emission factors of CH_4 in studied seasons
Rys. 2. Wartości wskaźnika emisji CH_4 w poszczególnych porach roku

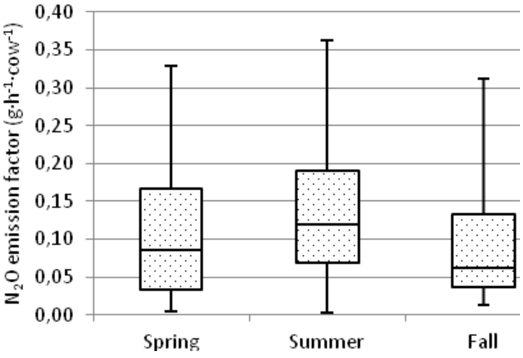


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Fig. 3. Emission factors of N_2O in studied seasons
Rys. 3. Wartości wskaźnika emisji N_2O w poszczególnych porach roku

The analysis of the seasons impact on greenhouse gas emission factors showed statistically significant differences (α=0.05). In the case of NH_3 and CH_4, there was no difference only for spring and summer (α=0.05). For N_2O emission factors the difference was not confirmed only for spring and fall (α=0.05). The highest mean value of NH_3 emission factor (1.17±0.45 g·h^{-1}·cow^{-1}) and N_2O emission factor (0.120±0.060 g·h^{-1}·cow^{-1}was observed during the summer, what was related to the high ventilation rate in barns. The lowest emission factors for those gases were in the fall and amounted 0.77±0.37 g·h^{-1}·cow^{-1} and 0.062±0.049 g·h^{-1}·cow^{-1}, respectively. CH_4 emission factor was the highest in the fall - 17.3±2.1 g·h^{-1}·cow^{-1}, and the lowest in the spring - 14.8±2.3 g·h^{-1}·cow^{-1}.

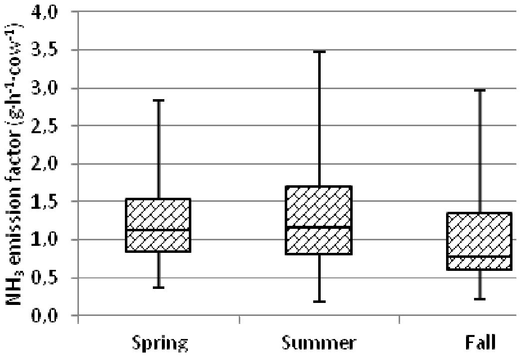

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Fig. 4. Emission factors of NH_3 in studied seasons
Rys. 4. Wartości wskaźnika emisji NH_3 w poszczególnych porach roku

4. Conclusions

1. The median of CH_4 emission factor was 14.8±2.3 g·h^{-1}·cow^{-1} in spring, 16.9±3.2 g·h^{-1}·cow^{-1} in summer, 17.3±2.1 g·h^{-1}·cow^{-} in fall. For N_2O and NH_3 values were 0.085±0.067 g·h^{-1}·cow^{-1} in spring, 0.120±0.060 g·h^{-1}·cow^{-1} in summer, 0.062±0.049 g·h^{-1}·cow^{-1} in fall and 1.13±0.34 g·h^{-1}·cow^{-1} in spring, 1.17±0.45 g·h^{-1}·cow^{-1} in summer, 0.77±0.37 g·h^{-1}·cow^{-1} in fall, respectively.
2. The analysis of the effect of the seasons (temperature and humidity conditions) on the emission of studied gases does not allow to formulate the clear conclusions. The differences in values of daily emission factors do not occur between the same seasons in each studied barns. It may suggest that apart weather parameters, also other factors like: the type of the building, housing system and manure removal system may affect the gases emission.
3. The analysis for all barns together showed statistically significant differences in greenhouse gas emission factors between seasons (α = 0.05). For NH_3 and CH_4, there was no difference only for spring and summer and for N_2O between spring and fall (α=0.05).

5. References

[1] Bluteau C.V., Massé D.I., Leduc R.: Ammonia emission rates from dairy livestock buildings in Eastern Canada. Biosystems Engineering, 2009, 103(4), 480–488.
[2] Calvet S., Gates R.S., Zhang G-Q., Estellés F., Ogink N.W.M., Pedersen S., Berckmans D.: Measuring gas emissions from livestock buildings: A review on uncertainty analysis and error sources. Biosystems Engineering, 2013, 116(3), 221–231.
[3] CIGR: 4th Report of working group on climatisation of animalhouses: Heat and moisture production at animal and house levels. Commission Internationale du Ge´nie Rural, Horsens, Denmark, 2002.
[4] Feidler A.M., Müller H.J.: Emissions of ammonia and methane from a livestock building natural cross ventilation. Meteorologische Zeitschrift, 2011, 20(1), 059–065.

[5] Joo H.S., Ndegwa P.M., Heber A.J., Ni J.-Q., Bogan B.W., Ramirez-Dorronsoro J.C., Cortus E.: Greenhouse gas emissions from naturally ventilated freestall dairy barns. Atmospheric Environment, 2015, 102, 384–392.

[6] KOBIZE: National emission balance of SO2, NOX, CO, NH3, NMLZO, particulate matter, heavy metals and TZO in SNAP and NFR classification. Basic raport, Warszawa, 2015.

[7] KOBIZE: Poland's national inventory report 2015. Greenhouse gas inventory 1988-2013, Warszawa, 2015.

[8] Koinakis C.J.: Combined thermal and natural ventilation modeling for long-term energy assessment: validation with experimental measurements. Energy and Buildings, 2005, 37(4), 311–323.

[9] Kolasa-Więcek A.: Modeling greenhouse gas emissions from livestock farming in Poland with the use of stepwise multiple regression. Journal of Research and Applications in Agricultural Engineering, 2013, 58(1), 78–85.

[10] Kolasa-Więcek A.: Prognozowanie wielkości emisji CH_4 z fermentacji jelitowej oraz hodowli zwierząt gospodarskich z wykorzystaniem sztucznej sieci neuronowej Flexible Byesian Models. Journal of Research and Applications in Agricultural Engineering, 2011, 56(2), 90–93.

[11] Mosquera J., Hol J.M.G., Monteny G.J.: Gaseous emissions from a deep litter farming system for dairy cattle. International. Congress Series, 2006, 1293, 291–294.

[12] 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. Atmospheric Environment, 2011, 45(37), 6760–6768.

[13] Pereira J., Misselbrook T., Chadwick D.R., Coutinho J., Trindade H.: Ammonia emissions from naturally ventilated dairy cattle buildings and outdoor concrete yards in Portugal. Atmospheric Environment, 2010, 44, 3413–3421.

[14] Rong L., Liu D., Pedersen E.F., Zhang G.: Effect of climate parameters on air exchange rate and ammonia and methane emissions from a hybrid ventilated dairy cow building. Energy and Buildings, 2014, 82, 632–643.

[15] Samer M., Ammon C., Loebsin C., Fiedler M., Berg W., Sanftleben P., Brunsch R.: Moisture balance and tracer gas technique for ventilation rates measurement and greenhouse gases and ammonia emissions quantification in naturally ventilated buildings. Building and Environment, 2012, 50, 10–20.

[16] Samer M., Loebsin C., Fiedler M., Ammon C., Berg W., Sanftleben P., Brunsch R.: Heat balance and tracer gas technique for airflow rates measurement and gaseous emissions quantification in naturally ventilated livestock buildings. Energy and Buildings, 2011, 43(12), 3718–3728.

[17] Schrade S., Zeyer K., Gygax L., Emmenegger L., Hartung E., Keck M.: Ammonia emissions and emission factors of naturally ventilated dairy housing with solid floors and an outdoor exercise area in Switzerland. Atmospheric Environment, 2012, 47, 183–194.

[18] Schulze T., Eicker U.: Controlled natural ventilation for energy efficient buildings. Energy and Buildings, 2013, 56, 221–232.

[19] Snell H.G.J., Seipelt F., Van Den Weghe H.F.A.: Ventilation rates and gaseous emissions from naturally ventilated dairy houses. Biosystems Engineering, 2003, 86(1), 67–73.

[20] Sommer S.G., Olesen J.E., Christensen B.T.: Effects of temperature, wind speed and air humidity on ammonia volatilization from surface applied cattle slurry. Journal of Agricultural Science, 1991, 117, 91–100.

[21] VanderZaag A.C., Flesch T.K., Desjardins R.L., Baldé H., Wright T.: Measuring methane emissions from two dairy farms: Seasonal and manure-management effects. Agricultural and Forest Meteorology, 2014, 194, 259–267.

[22] 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. Atmospheric Environment, 2012, 61, 232–243.

[23] 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. Biosystems Engineering, 2005, 92(3), 355–364.