Pol. J. Environ. Stud. Vol. 23, No. 4 (2014), 1107-1114

Original Research

Assessments of Biogenic Gas Emission Processes in Cowsheds

Rolandas Bleizgys, Ligita Baležentienė*

Aleksandras Stulginskis University, Studentų 11, LT-53361 Akademija,
Kaunas r., Lithuania

Received: 17 May 2013
Accepted: 30 January 2014

Abstract

Microclimatic factors rendering gas emissions from manure were evaluated during the four seasons throughout a year. The most favorable microclimatic conditions for the highest bacterial activity which fostered the NH_3 emissions from manure were observed in the insulated cowsheds. The temperature did not fall below 2.1ºC, whereas it rose up to 26.9ºC during summer, thus resulting in high air humidity. The most favorable microclimate is that of a cold cowshed: -14.1ºC to 29.5ºC, with the relative humidity fluctuating within the desirable limits even in the cold period. In a cowshed, the main air pollutant is NH_3; as for the other harmful gases, relatively low emissions were observed. The maximal rates of NH_3 emission were observed from surfaces littered with liquid manure as well as in loci where the urine accumulated. The highest NH_3 emission was observed from the floor littered with a liquid manure near the parlor – 342±21 $mg \cdot m^{-2} \cdot h^{-1}$ in a semi-deep cowshed. The following NH_3 emission factors per livestock unit (LU) per day (d) were estimated: box-type cold – 21.9±3.2 g $(LU\ d)^{-1}$, partially insulated box-type – 32.1±3.7 g $(LU\ d)^{-1}$, semi-deep cowshed – 30 8±4.3 g $(LU\ d)^{-1}$, and tie-cowshed – 27.4±2.9 g $(LU\ d)^{-1}$.

Keywords: temperature, humidity, NH_3, manure, cowsheds

Introduction

Environmental protection is becoming increasingly important in animal husbandry, which is an important source of environmental pollution [1, 2]. Cattle storage contributed to the most significant share of NH_3 emission, some 50% of which can be further decomposed accordingly to the animal type: pigs – 22%, poultry – 7%, mineral fertilizers – 18%, and horses, sheep and other animals – only 3% [3, 4]. The maximum NH_3 emissions intensity is 8.8 kg per cow per indoor 190-day period [5, 6]. The key issue is to limit the NH_3 concentration in a stable environment for it violates animal respiratory and eye mucous membranes, increases blood pressure, damages the heart, and reduces resistance to infectious diseases. In the atmosphere NH_3 converts into nitrogen and nitrite acids, thus damaging the whole ecosystem. Therefore, in order to reduce these emissions from livestock farming, one first needs to install green technologies in stables [7, 8].

The mitigating factors of NH_3 emissions are ventilation, cleanness, and humidity in a cowshed, and manure acidity, air and manure temperature, and protein content in manure [9, 10]. Though common patterns of NH_3 emissions are accorded, identifying the integrated impact of various factors is undervalued for analysis [11, 12]. The bio-filters were introduced to supress the NH_3 emissions emitted with air outgoing from the cowshed space [13-15]. However, these are not suitable in open cowsheds. Furthermore, the manure additives in both cowsheds and manure yard are analyzed [16]. It is estimated that sulphur acid addition and pH decline from 7 to 5.5, causing a reduction in NH_3 emissions by 80% [17, 18].

*e-mail: ligita.balezentiene@asu.lt

Swensson et al. [7] and Popescu et al. [19] have shown the relationship between NH_3 content and animal holding techniques in cowsheds: 4.3 ppm in tie-cowshed littered, 6.1 ppm in tie-cowshed no-littered, and 7.4 ppm in loose no-littered cowshed. According to those findings, rejecting the litter resulted in an NH_3 emissions increase. The emission also increased while keeping animals loose, for one animal pollutes more area. According to Zhang et al. [20], the NH_3 emissions ranged from 16 to 68 g $(LU\ d)^{-1}$ in loose keeping systems depending on the cowshed technological solutions, floor type, manure removal technological options, and temperature. The maximum NH_3 emissions occurred in livestock tracks with a floor made of rough solid concrete. NH_3 emissions can be reduced by 67% by installing sleek asphalt or a concrete floor with inclination toward a slurry channel. NH_3 emissions are 1.5 times higher in cowshed with a grated floor and manure-circulating channels than in those with solid concrete cowshed and properly built tracks. Thanks to the rise in temperature from 2 to 20ºC, the NH_3 emission intensity increased from 10 to 30 g $(LU\ d)^{-1}$, i.e. 3 times. As a result, from 9 kg NH_3 (sleek solid tracks and manure collection channels) to 28 kg NH_3 (jagged piece tracks) evaporated per year per cow place. Thereby, the NH_3 emissions depend mainly on the type of floor and method of manure removal.

It is important to maintain all the environmental factors within their limits of tolerance in the cowsheds. In particular, the relative humidity should not exceed 90% at 4ºC, 88% at 5ºC, and 72% at 15ºC as calculated by regression equation [21].

Nowadays, it is very important not only to reduce environmental pollution by gas, but also pollution to ensure that reduction shall not adversely affect the livestock welfare, i.e. the issues of environmental pollution and animal-friendly environment (animal welfare) must be addressed simultaneously. But it is still difficult to provide accurate data on NH_3 and other gas emissions per LU due to lack of equipment of reliable and accurate measurement of gas concentrations as well as measurement methods. Emissions from cold cowsheds are under-analyzed [22, 23].

Our research objective was to assess various microclimatic factors affecting the patterns of NH_3 emissions and substantiate the measures for minimizing the harmful gas emissions in cowsheds.

Materials and Methods

NH_3 emission research was carried out in cowsheds of the four types, viz. semi-deep insulated, insulated tie-cowsheds, box-type cold, and box-type partially thermally insulated (insulated cowshed roof only).

A semi-deep insulated cowshed wall built of ferrocement blocks and ceilings is insulated with a thick layer of straw (Fig. 1a). A box-type cold (sometimes only roof insulated) cowshed is most common in Lithuania and features an average heat transmission coefficient of 4.5 $W \cdot m^{-2} \cdot K^{-1}$. A shaft ventilation system is installed in cowsheds. Cow seedbed is littered with straw (1,450 kg per day, thus maintaining the thickness of the straw layer of 2-3 cm). Manure is removed once a month by means of mobile equipment.

The tie-cowshed is a typical old cowshed with 200 cows (Fig. 1b). The cowshed is equipped with two feeding tracks, with cows tied along both sides. The cowshed is insulated with straw stored on the roof overlay. A box-type

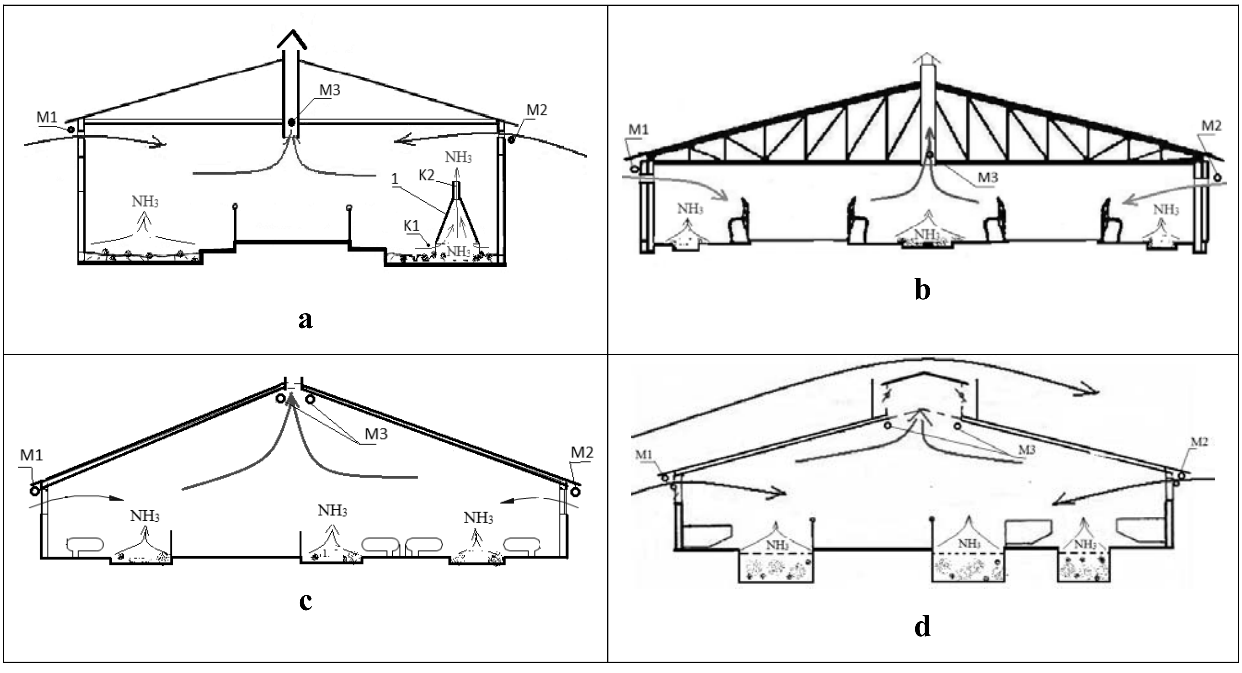

Fig. 1. Cowshed types and the scheme of microclimate research: a – semi-deep insulated, b – insulated tie-cowshed, c – box-type cold, d – partially insulated box-type, 1 – portable aerodynamic camera for gas emission measurement; M1, M2, M3 – relative air humidity, temperature measurement points; K1 – aerodynamic chamber for measurement of gas concentration in the air inflow (C_e, ppm), and K2 – measurement of air outflow velocity and gas concentration (C_o, ppm).

Table 1. Mean indices of cowshed microclimate and their minimum and maximum values (in brackets).

Cowshed type	Air temperature (ºC)			In cowshed	
	Outside	In cowshed	Difference	Relative humidity (%)	NH_3 content (ppm)
Semi-deep insulated	9.93 (-20.2-32.6)	14.2 (2.9 – 27.3)	7.2 (2.1 –21.4)	79.6 (69.4 – 100)	7.6 (4-9)
Insulated tie-cowshed	-3.9 (-22.6-15.5)	13.0 (6.2 – 21.6)	16.9 (2.5 –26.9)	84.1 (67.2 – 100)	9.6 (6-11)
Box-type cold	8.0 (-21.2-32.1)	12.1 (-14.1-29.5)	4.1 (1.4 – 11.6)	79.7 (47.5 – 98.5)	3.4 (2–5)
Partially insulated box-type	1.2 (-22.2-26.3)	9.6 (-2.3 – 3.2)	6.5 (1.6 – 20.8)	75.6 (49.2 – 98.1)	5.7 (3-9)

cold cowshed contains 220 cows (Fig.1c). The cowshed's walls and roof were uninsulated, the latter only capped with tin plate. Cows were kept in shallow box floors covered with rubber mats 30 mm thick. Walking tracks were covered by concrete, whereas the manure was removed by a scraper transporter. The cowshed was equipped with a non-channel, ridge-slit ventilation system. The air flowed in through wall slots covered with a grid and was removed through ridge holes. Air circulation was controlled by lifting the securer blind and changing the width of wall slots. The average wall and roof heat transmission coefficients were 3.3 W $(m^2 \cdot K)^{-1}$ and 0.45 W $(m^2 \cdot K)^{-1}$, respectively, in the partially insulated (insulated roof only) box-type cowshed of 230 boxes (Fig. 1d). The fresh air inflowed through the secure adjustable onwall openings, whereas the contaminated one was removed through regulated ridge slots. The no-littered technology was applied in the cowshed. The rest boxes were enclosed with lay rubber cover. The manure tracks were covered with a grid. 1.2 m-deep manure circulation channels were installed under the cow walking tracks. Manure was removed once a month on average.

The key microclimate variables (temperature, relative humidity, gas concentration) and NH_3 emissions were measured in the cowsheds at different times of the year. Emission intensity from different surfaces was measured at the mean annual temperatures in the cowshed. The measurement carried out in different seasons of the year lasted from 96 days in tie-cowshed to 148 days in box-type cold cowshed.

NH_3 emission intensity from the various surfaces in cowsheds was measured by applying the mass flow method using the aerodynamic chamber with a fan (15 $m^3 \cdot h^{-1}$). The gas concentrations at the constant air velocity and outflow-inflow rate were measured. The chamber was installed in various sites on the cowshed differently contaminated surfaces: the manure track, the tracks to the parlor, deep litter, etc. The measurements were performed in 10 replications. NH_3 emission (E) from contaminated surfaces was calculated using:

$$E = (C_o - C_e) \times G \tag{1}$$

...where: G – the intensity of the chamber ventilation ($m^3 \cdot h^{-1}$), C_e – gas concentration ($mg \cdot m^{-3}$) in the air inflow, and C_o – gas concentration ($mg \cdot m^{-3}$) from the air outflow. NH_3 emission values were recalculated for the animal place and the cowshed. The cow specific with the average weight and productivity equivalent to a livestock unit (LU) and dispenses ca. 1,000 W of heat into the environment. At the given NH_3 emission values per capita (NH_3 mg $LU^{-1} \cdot h^{-1}$), the cowshed ventilation intensity ($m^3 \cdot LU^{-1} \cdot h^{-1}$) was calculated by virtue of the following equation:

$$G_{NH_3} = \frac{E_{NH_3}}{C_c - C_e} \tag{2}$$

...where: C_c – limit of the permitted concentration of NH_3 in the cowshed air ($mg \cdot m^{-3}$), and C_e – NH_3 concentration in the inflow air ($mg \cdot m^{-3}$).

Intensity of the cowshed ventilation was calculated similarly according to CO_2 and water vapor content.

Gas concentration was measured by a gas analyzer Drager Miniwarn certified by the European Union, 94/9 EC Directive. Air temperature and relative humidity were recorded with 7 sensors (two outside and five inside) every hour with a computer-controlled temperature and humidity meter-storage device COX TRACER ALMEMO 2590-9. Air velocity was measured by Vane Anemometers ALMEMO FV A95-S120 in the aerodynamic chamber.

The confidence intervals of the estimates were obtained by employing one-way analysis of variance by ANOVA (in case of significant interactions), followed by post hoc Turkey theoretical criterion. The least significant differences between treatment means were determined using Fisher's least significant differences (LSD_{05}). LSD standard error (SE) has been calculated at a level of statistical significance $p < 0.05$.

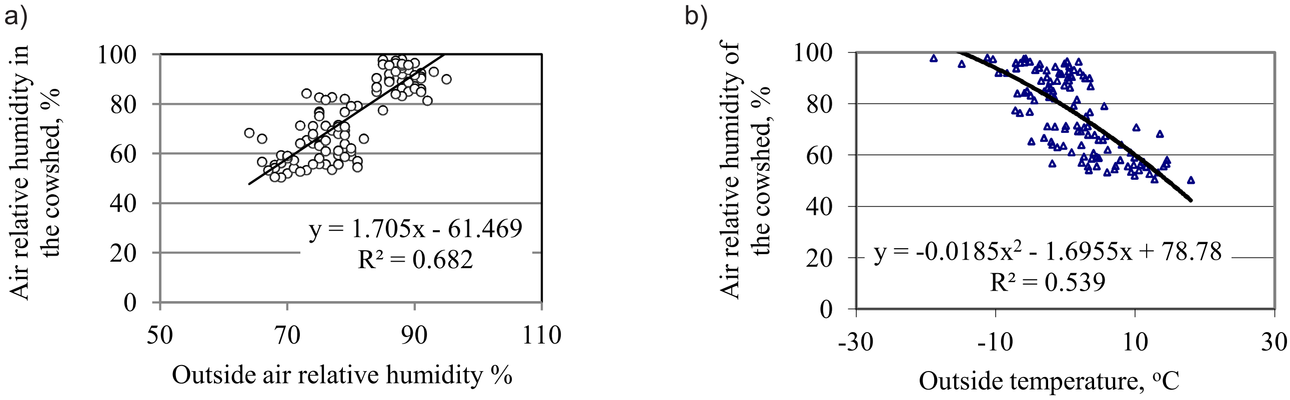

Fig. 2. Response of relative humidity to outside relative humidity (a) and air temperature (b) in a partially insulated box-type cowshed.

Results and Discussion

The observed outside temperature ranged between -22.6ºC and 32.6ºC in the various types of cowsheds (Table 1). Furthermore, the inside lowest temperature varied significantly across different cowsheds: it dropped to -14.1ºC in box-type cold, but that of 6.2ºC was maintained in a tie-cowshed (Fig. 1b). However, the highest temperature – 29.5ºC – was observed in the box-type cold cowshed. Different microclimates in the cowsheds were caused by different water vapour condensation on the walls of the cowshed construction induced by differences between inside and outside air temperatures. The condensation process has not been studied in detail. Indeed, the appearance of condensate on cowshed constructions was determined visually, i. e. by observing the emergence of water drops. This corresponded with Kavolelis et al. [25], who found that the difference between inside box-type cold cowshed and the outside temperature accounted for more than 6.2ºC) and induced condensation on the roof and inner wall surface, thus damaging not only cowshed construction but also the animal health.

The difference between the inside and outside temperature values might increase up to 11.6ºC if the cowshed roof is thermally insulated. The average difference between outside and inside temperatures varied across different cowshed types during this study: 4.1ºC in box-type cold, 6.5ºC in partially insulated box-type (insulated cowshed roof), and even 16.9ºC in tie-cowshed (Figs. 2-4).

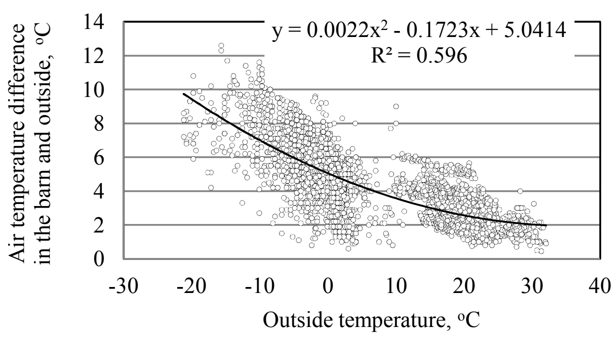

Fig. 3. The relationship between outside and inner box-type cold cowshed temperatures (warm season >10°C).

The outside weather conditions affected microclimate generally in partially insulated box-type cowshed (cowshed roof is insulated only) (Fig. 2b). It was found that a decreasing temperature induced a significant increase in air humidity due to changes in air circulation. According to Kavolelis [21], optimal air humidity should be equal to 88% at 5ºC. therefore, the observed relative humidity can be considered excessive (> 90%) during 34 days out of 125 days as a result of restrictions of airflow through the ventilation channels. Similar relationships were also observed in other cowsheds, when the outside temperature was falling. Again, the ventilation slots are excessively shut, therefore causing an increase in relative humidity.

The cowshed microclimate parameters, especially humidity, significantly declined during periods of frost. At outside temperatures below 0ºC the relative humidity was generally higher than 90% in the cowshed, i.e. greater than the permitted maximum. This occurred due to the too much or completely shut ventilation channels seeking to maintain a higher temperature in the cowshed.

The decreasing air exchange in the cowshed caused an increase in the difference between the outside and inside temperatures. During warm season the difference between the box-type cold cowshed and the outside temperature fluctuated between 1.5 and 2.1ºC (Fig. 3), though when the outside temperature dropped to -10ºC, the difference in temperature increases up to 6.4ºC. This slight difference in temperature indicated an adequate cowshed ventilation rate [25, 26]. Nonetheless, heat loss was avoided after ventilation intensity was reduced. Subsequently, temperature increased in cowsheds, nevertheless the humidity also increased. A large difference between the outside and the inside temperature was recorded there.

Throughout the research period the average difference between temperatures in the tie-cowshed and outside was 16.9ºC, whereas at frost season it rose to 26.9ºC. During frosts, the high difference in temperatures was observed in other heat-insulated cowsheds: up to 21.4ºC in semi-deep, and up to 20.8ºC in box-type. Such temperature differences induced the water vapour condensation observed on insulated roof structures. These cowsheds are considered to make very good conditions for bacteria activity, even dur-

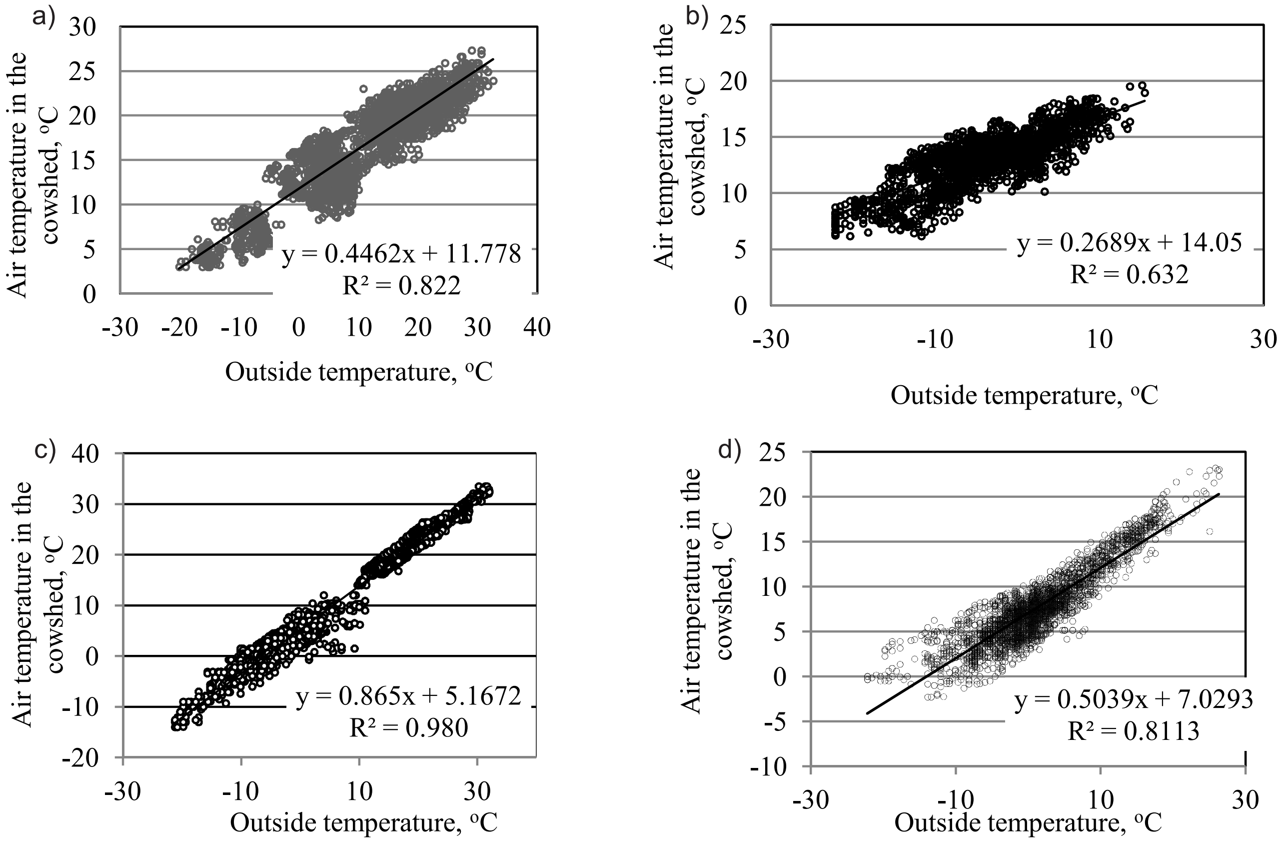

Fig. 4. Inside and outside temperature relationship in cowsheds of different types: a – semi-deep, b – tie-type, c – box-type cold, d – partially insulated box-type.

ing periods of frost due to the warmth and humidity in the cowshed. Such a microclimate supports gas emissions from manure. The significant dependence (r=0.8-0.9) of the inside temperature on outside temperature across the various cowshed designs was determined after estimating the linear regression equations (Figs. 3 and 4).

During the assessments of NH_3 emissions in different cowsheds, the inside temperature was close to the average temperature: 10.4±0.9°C in cool box-type, 8.3±0.7ºC in partially insulated box-type, 12.5±1.1ºC in insulated semi-deep, and 13.4±1.0ºC in insulated tie-cowshed. The maximal NH_3 emission emerged from surfaces covered with liquid manure or from pools of urine in a semi-deep cowshed (Fig. 5). NH_3 emission was equal to 342±21 mg·(m²·h)⁻¹ from liquid manure in the parlor, and 223±6 mg·(m²·h)⁻¹ from flouted semi-liquid manure on the cattle track. The lowest NH_3 emission (only 32±3 mg·(m²·h)⁻¹) was observed over a thick litter layer. Keeping animals on deep litter as well as choosing the right litter thickness is conceivable to reduce the NH_3 emission contribution to the environment, as the thick litter layer absorbs moisture and slurry, thus reducing humidity and evaporation. Deeper straw litter is able to reduce NH_3 emissions both in the cowshed and the manure yard. NH_3 emissions and concentrations do decline when applying peat litter, which acidifies manure (pH decreased) as well as bonded ammonia chemically. Therefore, the manure, especially slurry, is required to be removed from the cowshed in order to prevent the diffusion of ammonia, for they constitute the main sources thereof [27]. Slurry can be removed by installing flush manure channels. The slurry fallen into a channel is taken to the slurry tank by a water stream.

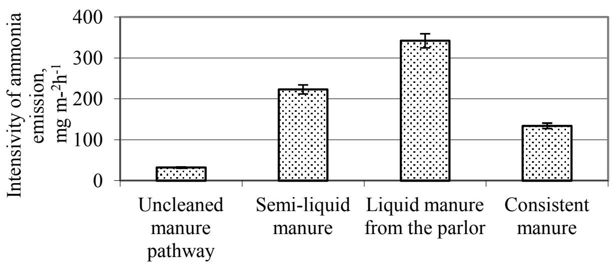

Fig. 5. NH_3 emissions from different surfaces in a semi-deep cowshed (mean±SE).

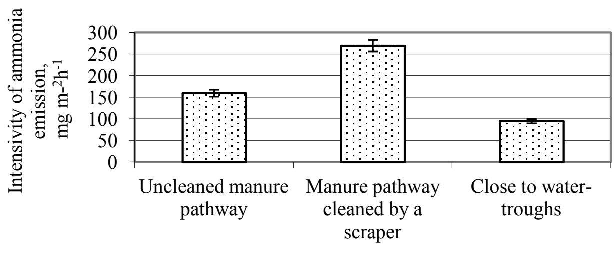

Fig. 6. NH_3 emissions from different surfaces in a box-type cowshed (mean±SE).

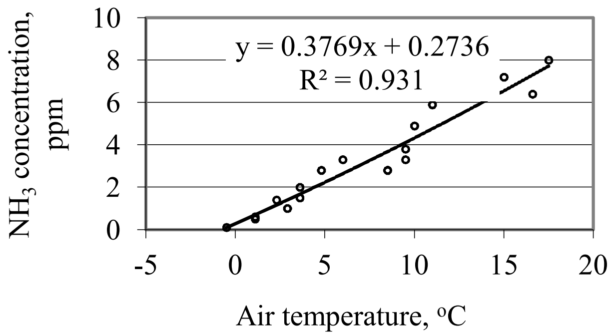

Fig. 7. Influence of temperature on NH_3 concentrations in box-type cowsheds.

The highest 268±27 mg·(m²·h)$^{-1}$ NH_3 emission was observed in a box-type cold cowshed, over the manure runway where manure is pushed out by a scraper transporter (Fig. 6). If the manure accumulated is not mixed (transporter does not move), the NH_3 emission decreases about two-fold.

After measuring manure-contaminated areas in cowsheds and evaluating the NH_3 emissions from various contaminated surfaces, we calculated that the following daily NH_3 emissions per cow emerged in the different cowshed environments: 21.9±3.2 g·(LU d)$^{-1}$ in a box-type cold (10.4ºC), 32.1±3.7 g·(LU d)$^{-1}$ in a partially insulated box-type (8.3ºC), 30.8±4.3 g·(LU d)$^{-1}$ in a semi-deep (12.5ºC), and 27.4±2.9 g·(LU d)$^{-1}$ in a tie-cowshed (13.4ºC). The largest manure-contaminated area covered 5.8 m²·LU^{-1} in semi-deep cowshed, 4.2 m²·LU^{-1} in a partially insulated box-type cowshed, 3.9 m²·LU^{-1} in a box-type cold, and only 1.1 m²·LU^{-1} in a tie-cowshed.

Significantly lower intensity of NH_3 emissions was observed in a box-type cold cowshed compared to those in other cowsheds. Differences in emissions across insulated semi-deep and partially insulated box-type cowsheds was low, though the manure-contaminated area differed by nearly 50%. Although the manure-contaminated surface in tie-cowshed was 5.2 times smaller than that in other cowsheds, the NH_3 emission intensity per cow place here was only some 15% lower than in a semi-deep or partially insulated box-type cowshed, but even higher compared with the cold box cowshed. This variation of NH_3 emission intensity across cowsheds was determined by the dry matter content of the manure, air temperature, and humidity. The latter parameters influenced not only the activity of the bacteria, but also the intensity of crust formation on the manure surface. Air temperature was similar in all cowsheds during the research, but it was changing throughout the year in diverging ways. Temperature was near 0ºC in cold and box-type cowsheds in winter. At that time, NH_3 gas concentrations fluctuated around 0 ppm (Fig. 7). However, temperature did not fall below 3.0ºC in the insulated tie-cowshed, even at -21ºC outside. Therefore, NH_3 is emitted from manure throughout the whole year in this cowshed type. Even though an increase in the polluted area stimulated NH_3 emission in loose keeping cowsheds, the lower temperatures reduced it.

The outside temperature strongly influenced NH_3 emissions from manure in the cowshed. We did identify the indirect evidence of cowshed temperature impact on NH_3 emissions for the reason that changing temperature caused alterations of weather circulation. Specifically if the temperature decrease reduced NH_3 concentration significantly due to decreased cowshed emissions (Fig. 7).

When cowshed temperature fell to 0ºC, NH_3 concentration was near 0 ppm. When the inside temperature rose by 1ºC, NH_3 emissions increased by 2.6% in the cowshed. These data correspond with findings of Duinkerken et al. [12], which state that emissions increased significantly in the summer. The following NH_3 emission rates were obtained for a 210-day stable period at the temperature ranging between 8.3 and 13.4ºC: 6.47 kg·LU^{-1} in a semi-deep cowshed, 4.60 kg·LU^{-1} in a box-type cold, 6.74 kg·LU^{-1} in a partially insulated box cowshed, and 5.75 kg·LU^{-1} in a tie-cowshed.

In summary, the cowshed air is mostly polluted with NH_3 gas. Furthermore, the high water vapour concentration was observed. The main indicators describing air pollution were NH_3 emission rate and NH_3 concentration. These values generally depend on construction type, state of livestock tracks, manure removal systems, and indoor air temperature. The remaining harmful gases were emitted from manure at relatively low rates. The rates of only 2 ppm for hydrogen sulphide H_2S, and 0.5 ppm for NO gas were detected in the partially insulated box-type cowshed, where liquid manure accumulated in the channels. In order to reduce NH_3 air pollution from the cowshed, it is advisable to remove manure, especially slurry, from the cowshed as soon as possible. It also is appropriate to reduce the walking tracks area. Manure removal from the cowshed to manure storage should avoid contact with the ambient air; similarly, it must be mixed as little as possible. In the case of the smooth and unlittered or low littered cowshed floor, their surface must be flat (without hollows or grooves) so that the urine flows into the channel. One should not use plank beds because the urine gathers underneath. When keeping the cattle on deep litter (preferably on peat) one needs to remove manure at the end of the winter in order to reduce harmful emissions and bacterial growth induced by the rising temperature in the cowshed and manure.

Reduction of environmental pollution must not adversely affect animal welfare, i.e. the issues of environmental pollution and animal-friendly environment (animal welfare) issues need to be dealt with together. Therefore, the most natural conditions for cattle lying down and walking must be maintained. Livestock should be kept loose, even in small herds. Tied cattle keeping should be avoided due to bad microclimate during winter. When the animals remain loose, they are not sensitive to the cold, and thus uninsulated cowsheds are recommended. Such cowsheds have good microclimate with the lowest air pollution.

If air humidity remains within the permitted limits, a small carbon footprint and NH_3 concentration will also be ensured [13]. We discovered that maximum intensity of the cowshed ventilation rate of 180.5 $m^3 \cdot (h\ LU)^{-1}$ is required to remove the surplus water vapor. Cowshed ventilation intensity of 102.8 $m^3 \cdot (h\ LU)^{-1}$ and from 53.9 to 91.8 $m^3 \cdot (h\ LU)^{-1}$ is necessary to remove the excess carbon dioxide and NH_3, respectively (depending on the cow-keeping technology).

Conclusions

Insulated cowsheds facilitate the best microclimate conditions for bacterial activity, thus stimulating NH_3 emissions from manure. The temperature here does not fall below 2.1ºC, but rises up to 26.9ºC during summer heat, often with a high relative humidity. The best microclimate was observed in the cold cowshed. The temperature ranged between -14.1ºC and 29.5ºC, but relative humidity remained within the permitted limits even during frost. The maximal NH_3 emission was recorded from the surface contaminated with liquid manure and where urine accumulated. The highest 342±21 and 223±16 $mg \cdot (m^2 \cdot h)^{-1}$ NH_3 rates were emitted from floors contaminated with liquid manure at the parlor and from semi-liquid manure on the cattle track, respectively, in the semi-deep cowshed. The lowest NH_3 emission rate, only 32±3 $mg \cdot (m^2 \cdot h)^{-1}$, was observed above a thick litter layer. NH_3 emission rates per day per cow place depended on cowshed type and temperature. In order to reduce NH_3 pollution from cowsheds, the following recommendation should be implemented:

- cows are kept in cold cowsheds;
- the lower temperature and drier air should be maintained by the means of sufficient ventilation;
- livestock manure removed as soon as possible (especially slurry);
- reduce the walking track area.

References

1. IPCC. Climate Change. The Physical Science Basis, Summary for Policymakers, Contribution of WG1 to the 4th Assessment Report of the IPCC, IPCC secretariat Switzerland. **2007**.
2. BEAUCHEMIN K.A., JANZEN H.H., LITTLE S.M., MCALLISTER T.A., MCGINN S.M. Life cycle assessment of greenhouse gas emissions from beef production in western Canada: A case study. Agr. Syst. **103**, 371, **2010**.
3. MENDEN B. Reduction of ammonia emission in agriculture, KTBL: Hannover, pp. 179, **1993** [In German].
4. CIGR. Climatization of Animal Houses. Forth report of working group, Danish Institute of Agricultural Sciences, Research Centre, Bygholm, **2002**.
5. SWIESTRA D., BRAM C.R., SMITS M.C. Grooved floor system for cattle keeping: ammonia emission reduction and good slip resistance, Am. Soc. Agric. Eng. **17**, (1), 85, **2001**.
6. AGUERRE M.J., WATTIAUX M.A., HUNT T., LOBOS N.E. Effect of nitrogen content and additional straw on changes in chemical composition, volatile losses, and ammonia emissions from dairy manure during long-term storage. J. Dairy Sci. **95**, 6, 3454, **2012**.
7. SWENSSON C., GUSTAFSSON G. Characterization of influence of manure handling system and feeding on the level of ammonia release using simple in cow houses. Anim. Sci. **52**, (2), 49, **2002**.
8. HARTUNG E., MARTINEC M., JUNGBLUTH T. Reduction of ammonia and odor emissions from animal husbandry agriculture through biological air filters, Final report on the research project, Universität Hohenheim: Stuttgart, pp. 32-46, **1997** [In German].
9. HARTUNG E. Design, implementation and evaluation of a test facility for the development and differentiated assessment of housing systems for fattening pigs, Habilitationsschrift, Universität Hohenheim, Stuttgart, pp. 120, **2001** [In German].
10. SHAH S.B., GRABOW G.L., WESTERMAN P.W. Ammonia adsorption in five types of flexible tubing materials. Appl. Eng. Agric. **22**, (6), 919, **2006**.
11. HAHNE J., HESSE D., VORLOP K.D. Trace gas emissions from pig fattening, Landtechn. **54**, (3), 180, **1999** [In German].
12. DUINKERKEN G., SMITS M.C.J., SEBEK L.B.J. VEREIJKEN P. F. G., ANDRE G., MONTENY G. J. Ammonia emission from the cow cowshed in a dairy farm system with limited grazing in relation to milk urea concentration. Practical Sci. Rep. 46, UR: Wageningen pp. 192, **2004**.
13. CASEY J.W., HOLDEN N.M. Quantification of GHG emissions from sucker-beef production in Ireland. Agr. Syst. **90**, 79, **2006**.
14. JUNGBLUTH T., HARTUNG E. What do biofilter? Landtechnik. **53**, (5), 264, **1997** [In German].
15. MARTINEC M., HARTUNG E., JUNGBLUTH T. Comparison of different filter materials for biofilters. Landtechnik. **54**, (2), 106, **1999** [In German].
16. HARTUNG E. Biofilter. Landtechnik. **58**, (3), 218, **2003** [In German].
17. NIMMERMARK S. Odour release, dispersion and influence on human well-being with specific focus on animal production. Doctoral thesis, Swedish University of Agricultural Sciences: Alnarp, pp. 60, **2004**.
18. GU W., ZHANG F., XU P., TANG S., XIE K., HUANG X., HUANG Q. Effects of sulphur and *Thiobacillus thioparus* on cow manure aerobic composting. Bioresource Technol. **102**, 6529, **2011**.
19. POPESCU S., BORDA C., El MAHDY C. I., DIUGAN E.A., SANDRU D. C., SPINU M., STEFAN R. Survey on Ammonia Concentrations in Dairy Cattle Tie-Stall Cowsheds. Anim. Sci. Biotechn. **44**, (1), 504, **2011**.
20. MICHAEL J., GIBSON J., TREVORS T., OTTEN L. Population estimates of *Thiobacillus thioparus* in composting biofilters by PCR analysis. J. Microbiol. Meth., **65**, 346, **2006**.
21. KAVOLELIS B. Planning rules and advice of technology cattle farms (in Lithuania). Raudondvaris, Lithuania, Melga Press, 88. **2006** [In Lithuanian].
22. ZHANG G., STROM 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**.
23. SCHULZ L. Development and applications of microelectronic sensors (electronic noses) for detecting emissions from livestock, Forschungsberichte: Bonn, pp. 79, **2000** [In German].
24. FREDERICK K., HAUTALA M., PASTELL M., PRAKS J., VEERMAE I., POIKALAINEN V., PAJUMAGI A., KIVINEN T., AHOKAS J. Microclimate and ventilation in

Estonian and Finnish dairy buildings. Energ. Buildings. **40**, (7), 1194, **2008**.
25. KAVOLELIS B., BLEIZGYS R., CESNA J. Emission of water vapour in uninsulated cowshed. Ann. Anim. Sci. **10**, (1), 57, **2010**.
26. VERGE X.P.C., De KIMPE C., DESJARDINS R.L. Agricultural production, greenhouse gas emissions and mitigation potential. Agr. Forest Meteorol. **142**, 255, **2007**.
27. STEWART A.A., LITTLE S.M., OMINSKI K.H. WITTENBERG K.M., JANZEN H.H. Evaluating greenhouse gas mitigation practices in livestock systems: an illustration of a whole-farm approach. J. Agr. Sci. **147**, 367. **2009**.