Indoor climate of pigsty with deep litter and liquid manure system in summer

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Abstract. Construction of big deep-litter pigsties and pigsties without litter (using liquid manure systems) is becoming more extensive. Due to lack of knowledge concerning animal-keeping in big pigsties, it has become necessary to study the work environment in pigsties and, in particular, their indoor climate. In order to determine the impact of the outdoor climate, different methods for animal-keeping and tending activities on indoor climate during summertime, the air temperature, relative humidity, air velocity and contents of oxygen, carbon dioxide and ammonia were measured on a daily basis at the height of 1.5 m from the floor above the pigsty in the centre of deep-litter (800 fattening pigs) and liquid manure system (600 young pigs) pigsties. Simultaneously outdoor air temperature and relative humidity were measured. Data Logger equipment with relevant sensors and Gas Monitor Pac III were used for studying the indoor climate. Hydrolog equipment was used for measuring the parameters of outdoor climate. Measurement results were processed by using computer programmes AMR Win Control, HW3 and MS Excel.

It turned out that during summertime the indoor climate of pigsties was most affected by outdoor climate and tending works. The daily average indoor temperature (17.04 and 17.60°C respectively; outdoor temperature, 18.15 and 8.75°C) and relative humidity (68.11 and 78.59% respectively; outdoor relative humidity, 71.88 and 84.19%) remained within recommended limits for animals in the deep-litter pigsty and in the pigsty without litter. However, partial floor heating had to be used in the morning in order to ensure optimum indoor temperature and relative humidity in the pigsty for young pigs. Due to good ventilation in the pigsties the daily average contents of carbon dioxide (0.06 and 0.07%) and ammonia (20.9 and 8.7 ppm) remained within standard limits. Ammonia content in pigsties was higher during tending works, reaching 43 and 27 ppm. As a result of the study, the graphical and empirical relationship was determined between ammonia concentration and indoor air both in terms of air temperature and combined effect of temperature and relative humidity.

Key words: air temperature, air velocity, relative humidity, oxygen, carbon dioxide, ammonia, outdoor climate, tending activities, ventilation, Data Logger

INTRODUCTION

A pig farm represents a biotechnical system, „man-machine-animal", which together with the indoor climate of buildings or premises constitutes a work environment for producing animal products. Indoor climate parameters of the working environment have an impact on the human capacity for work (Liiske et al., 1998; Liiske, 2002; Sada & Reppo, 2006) and productivity of animals (Mothes, 1977; Liiske, 2002). Humidity and ammonia have harmful effects on the premises (Tuunanen &

Karhunen, 1986), whereas the indoor climate depends on various factors such as applicable tending technology, number of animals, systems for providing animals with forage, water and removal of manure, use of litter, and season or outdoor climate (Mothes, 1973; MWPS-33, 1989; Kender et al., 1998; Sada & Reppo, 2006).

There are old pigsties that have been rebuilt where animals are kept on litter in group stalls (fattening pigs, young pigs) or in farrowing stalls (sows). But there is a tendency towards building bigger pig farms, including those without litter, i.e. pigsties with liquid manure removal. The construction of new deep-litter pigsties has also started.

Enlargement of pigsties is accompanied by problems regarding achievement of required indoor climate of the working environment (increase of air humidity, contents of carbon dioxide and ammonia in winter, overheating of premises in summer, etc.). There are additional concerns emanating from the European Union, such as the ethical production quality and assurance of acceptable odour in ambient air.

Research on pigsties has mostly been focused on the air temperature, relative humidity, air velocity and – to a certain extent – gas composition (Mothes, 1973; Tuunanen & Karhunen, 1984; Karhunen, 1994), providing a basis for designing ventilation systems for relevant premises. Generally, such research has been carried out in small pigsties for up to 500 pigs and in customized laboratories (Tuunanen & Karhunen, 1986). Gas composition, its variation on a daily basis and its dependence on applicable animal-keeping methods and technologies have been studied to a lesser extent.

Due to extensive construction of big pig farms without litter and deep-litter pigsties, which use liquid manure systems, it has become necessary to study indoor climate in such pigsties. To determine the impact of outdoor climate and different methods for animal-keeping on indoor climate during summertime, the air temperature, relative humidity, air velocity and contents of oxygen, carbon dioxide and ammonia were measured on a daily basis in deep-litter and liquid manure system pigsties. Parallel to the observation of animal behaviour, the pig-tenders' activities were observed and outdoor air temperature and relative humidity were measured.

Data Logger equipment with relevant sensors and computer programme AMR Win Control were used for studying indoor climate; content of ammonia was measured by using Gas Monitor Pac III equipment and computer programme GasVision v5.7.3; outdoor air temperature and relative humidity were measured by using Rotronic Logger equipment and computer programme HW3.

Study results provide further information concerning the indoor climate in deep-litter pigsties and pigsties without litter and also allow selecting the method for the keeping of animals with the least harmful tending environment.

MATERIALS AND METHODS

Indoor climate was studied in pigsties for 800 fattening pigs and 600 young pigs, which are hereafter referred to as Pigsty A and Pigsty B (Table 1). Pigsties are made of silicate bricks and reinforced concrete. Fattening pigs and young pigs were fed with dried fodder delivered by automatic conveyor from automatic feeders. Automatic conveyor Big Dutchman was used in Pigsty A and the Roxcell device was used in Pigsty B. In Pigsty A fattening pigs (50 pigs per pen) were kept on deep litter with straw (the thickness of the litter varied 0.2–0.8 m); the manure was removed with a shovel-loader after replacing fattening pigs in the pigsty. In Pigsty B the liquid manure system was used: manure was removed from the pen holding 20 young pigs into a channel below the grated floor, drained away from the channel to a pump-room, where it was pumped to manure storage. Sucklers were used as the drinking device in both pigsties. Ventilation was regulated by automatic forced ventilation.

Table 1. Data on pigsties.

Item	Pigsty A	Pigsty B
Number of pigs	800 fatlings (25–100 kg)	600 young pigs (15–50 kg)
Way of handling	Deep-litter	Liquid manure system
Ventilation	Compulsion ventilation	Compulsion ventilation
Air flow control	Automatic	Automatic
Heating	Missing	Floor watering heating
Fodder delivery	Dry food automatic system Big Dutshman	Dry food automatic system Roxcell
Manure disposal	With tractor	Liquid manure, with flow for the Pumping-station
Watering	Nipple	Nipple
Litter	Straw	Missing

The methods of the study were based on the Health Protection Act of the Republic of Estonia (https://www.riigiteataja.ee...25048) and Finnish standards (Karhunen, 1992), according to which the numerical values of indoor climate parameters of a work environment can be measured at the height of 1.5 m for a human workplace. In order to study daily changes in indoor climate of pigsties in relationship to outdoor climate, methods for animal-keeping, performance of technological processes, activities of the tender and animal behaviour, the air temperature, relative humidity, air velocity and contents of oxygen, carbon dioxide and ammonia were measured on a daily basis at the interval of 60 seconds in the central part of the pigsties at the height of 1.5 m from the floor of the pigsty in summer (17.08–21.08.2007). Simultaneously outdoor air temperature and relative humidity were measured throughout the 24-hour period.

ALMEMO Data Logger 8990-8 equipment with relevant sensors was used for studying the indoor climate.

Air temperature and relative humidity were measured with AMR-manufactured sensor FH646-1 with measurement area 20–80°C (measuring accuracy 0.01°C) and 5–98% (measuring accuracy 0.1%), respectively. Oxygen sensor FY 9600-O_2 and ZA9000-AK2K are manufactured by AMR; their measurement area is 0–100% and measuring accuracy is 0.01%. Carbon dioxide content was measured with sensor FY A600-CO_2 with measurement area 0–2.5% and measuring accuracy 0.01%. Air velocity was measured by using thermo-anemometer FHA645TH2 with measurement area 0–2.0 m s^{-1} and resolution 0.001 $m \cdot s^{-1}$. Ammonia content was measured with Gas Monitor Pac III equipment manufactured by Dräger Safety AG & Co KGaA: its measurement area was 0...250 ppm and measuring accuracy 1 ppm. HygroLog device manufactured by Rotronic and HygroClip S sensor were used for measuring outdoor temperature and relative humidity (measurement area –40 - +85°C and 0–100%, accuracy ±0.3°C and ±1.5% respectively). Measurement results were analysed by using computer programmes AMR WinControl, Pac III Software 3.nn, HW3 (AHLBORN, 2007/2008; Dräger, 2001) and statistically processed by using programme MS Excel (Kiviste, 1999).

In order to exclude the impact of tending activities on the indoor climate, the dependence of ammonia content on the air temperature and relative humidity of the pigsties was determined by using numeric values of relevant parameters. However, these parameters were measured during the "rest" time of pigs. Results were processed by using computer programme SAS (SAS Online Doc, 2007).

RESULTS AND DISCUSSION

Depending on the type, age and live weight of animals, the recommended value of air temperature in pigsties varies by different national standards and sources of reference (Tuunanen & Karhunen, 1984; Maatalouden..., 1990), ranging from +5 to +32°C. Recommended minimum indoor air temperature for fattening pigs is +7 to +15°C, maximum temperature +25 to +27°C and optimal temperature +15 to +22°C (Rosti, 1988; CICR, 1984; Maatalouden..., 1990). Recommended relative humidity is between 50–80% (Maatalouden...1990), but should not exceed 85%, because excess moisture generates dripping water on the ceiling, walls and floor of the building, which is usually accompanied by deterioration of other indicators of indoor climate. Low air humidity content (less than 55%) may cause drying of oral mucous membranes in animals and generates dust on the premises (Mothes, 1974; Veinla, 1986). Rosti (1988) recommends that the relative humidity of indoor air in summer should be 50–75%.

Study results (Figs 1–4; Table 2) reveal that average daily temperatures measured both in the deep-litter pigsty, or Pigsty A, and the liquid manure system pigsty, or Pigsty B (17.04 and 17.60°C respectively) remained within recommended limits, ranging from 12.80 to 22.10°C in Pigsty A and from 14.17 to 21.11°C in Pigsty B over the 24-hour period.

The relative humidity of indoor air in the pigsties also remained within recommended limits: 68.11 and 78.59% respectively. However, it should be noted that partial floor heating was required for maintaining optimal indoor temperature and humidity in Pigsty B, where the outdoor temperature was relatively lower (1.2–21.2°C) and relative humidity was higher (43.4–100%) than in Pigsty A. The results concerning the indoor climate of Pigsty A (Figs 1, 2) indicate significant impact of temperature and relative humidity of outdoor air on indoor climate. Thus the higher daytime temperature of outdoor air 24.5°C (Fig. 2) increased the indoor temperature of the pigsty to 22.10°C, while remaining within optimal range (Maatalouden..., 1990). But the outdoor temperature measured in the early morning (12.2°C) reduced the temperature of indoor air of the pigsty to 12.80°C, which was lower than optimal, but still remained within the allowed lower limits for young pigs. This also explains the differences in the daily air temperature in pigsties that are partially heated or not heated in summer that exceed the recommended value by 2–3°C (Maatalouden... 1990).

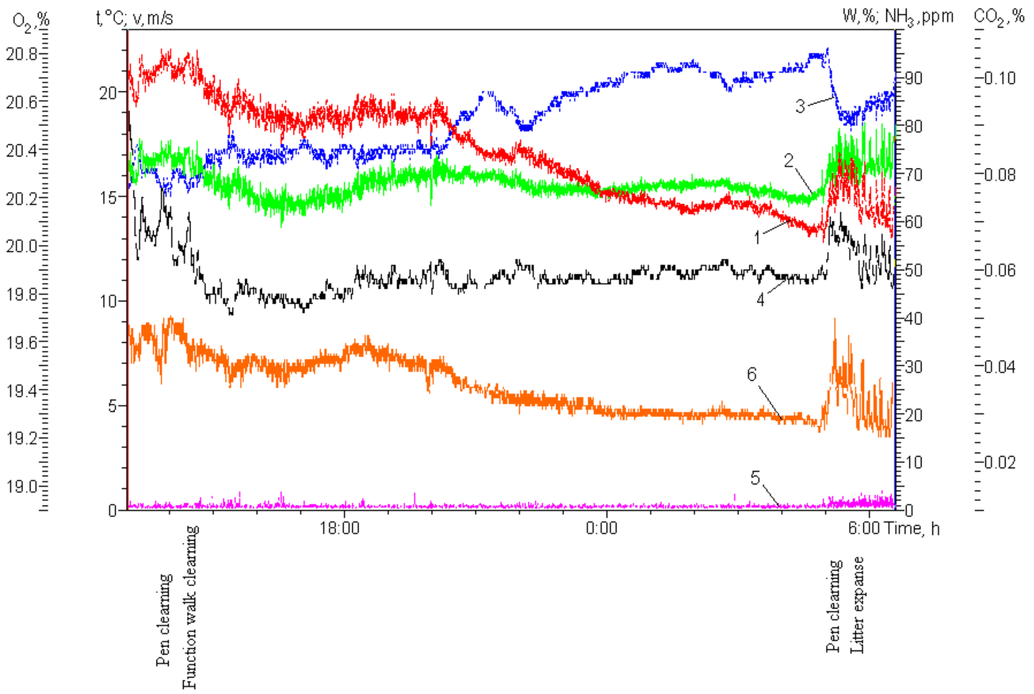


Fig. 1. Daily change of numeric values of indoor climate parameters in Pigsty A: 1– temperature, 2– relative humidity, 3– oxygen, 4– carbon dioxide, 5– air velocity, 6– ammonia.

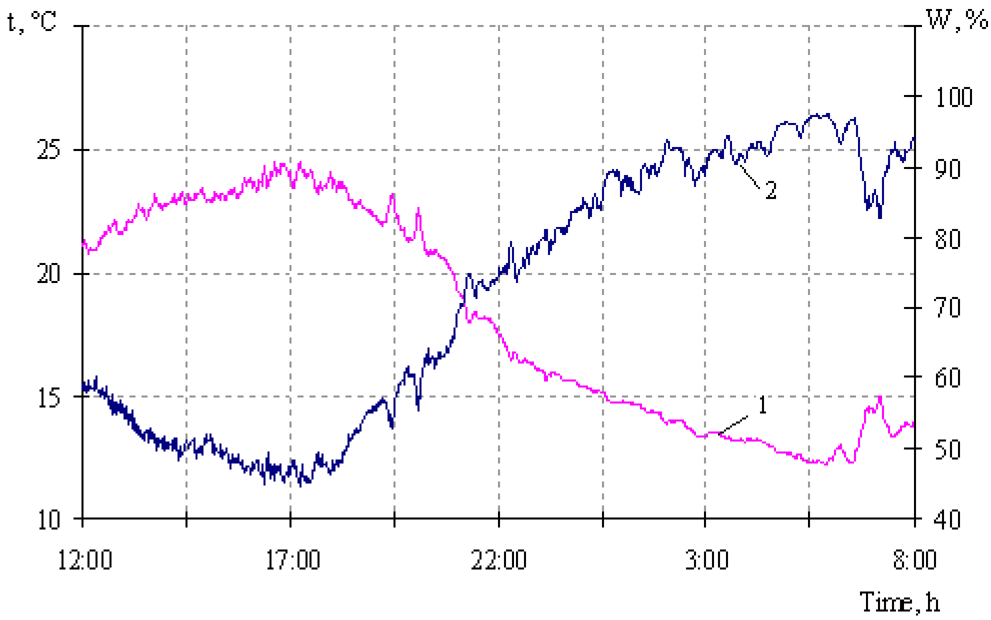


Fig. 2. Outdoor temperature (1) and relative humidity (2) near Pigsty A.

It appears (Figs 1, 2) that the relative humidity of the indoor air of the pigsty is also dependent on the humidity of outdoor air, being virtually equal (68.11 and 71.88% respectively) in the case of intensive ventilation (average air velocity 0.17 m s^{-1}).

Animal respiration and the processes occurring on the surface of manure cause the generation of carbon dioxide and ammonia, which are considered harmful gases (Rosti, 1988). The sources of reference and standards provide differing information concerning the concentration limits of carbon dioxide. According to German researcher Mothes (1973) the maximum allowed concentration of carbon dioxide is 0.35% in the air zone of animals and 0.50% in human work zone, whereas pursuant to Finnish data (Maatalouden..., 1990) human evaluation of air deteriorates in the case of a concentration of 0.1% and ventilation is necessary in the case of 0.25%. Pursuant to the occupational health and safety requirements the carbon dioxide content of 0.5% is considered harmful for humans (Seppänen, O. & Seppänen, M., 1998). Pursuant to the standards applicable in the Republic of Estonia (http://riigi-teataja...73153) the content of carbon dioxide allowed in the air of human environment is up to 0.5%. Average content of carbon dioxide in the pigsties subject to study was 0.06 and 0.07%, increasing to 0.09 in Pigsty A and to 0.14% in Pigsty B during tending works. The higher the content of carbon dioxide, the lower the oxygen content (Figs 1, 3).

Table 2. Indoor climate parameter values in the pigsties.

Measured parameters	Min	Max	Average $\bar{x}$	Standard deviation σ	Standard error σ_x
		Pigsty A			
Temperature, °C	12.80	22.10	17.04	2.344	0.030
Relative humidity W, %	58.9	80.5	68.11	3.025	0.038
Oxygen O_2, %	20.20	20.82	20.53	0.158	0.002
Carbon dioxide CO_2, %	0.05	0.09	0.06	0.005	0.000
Ammonia NH_3, ppm	6	43	20.9	8.008	0.101
Air velocity v, m/s	0.086	0.981	0.17	0.079	0.001
Outdoor temperature, °C	12.2	24.5	18.15	4.313	0.124
Outdoor relative humidity, %	44.5	97.7	71.88	18.549	0.535
		Pigsty B			
Temperature, °C	14.17	21.11	17.60	1,885	0,021
Relative humidity W, %	63.9	90.0	78.59	2,984	0,033
Oxygen O_2, %	19.92	20.70	20.38	0,170	0,002
Carbon dioxide CO_2, %	0.05	0.14	0.07	0,007	0,0001
Ammonia NH_3, ppm	4	27	8.7	4.491	0.050
Air velocity v, m/s	0.085	1.552	0.25	0.136	0.002
Outdoor temperature, °C	1.2	21.2	8.75	4.423	0.114
Outdoor relative humidity, %	43.4	100.0	84.19	15.430	0.398

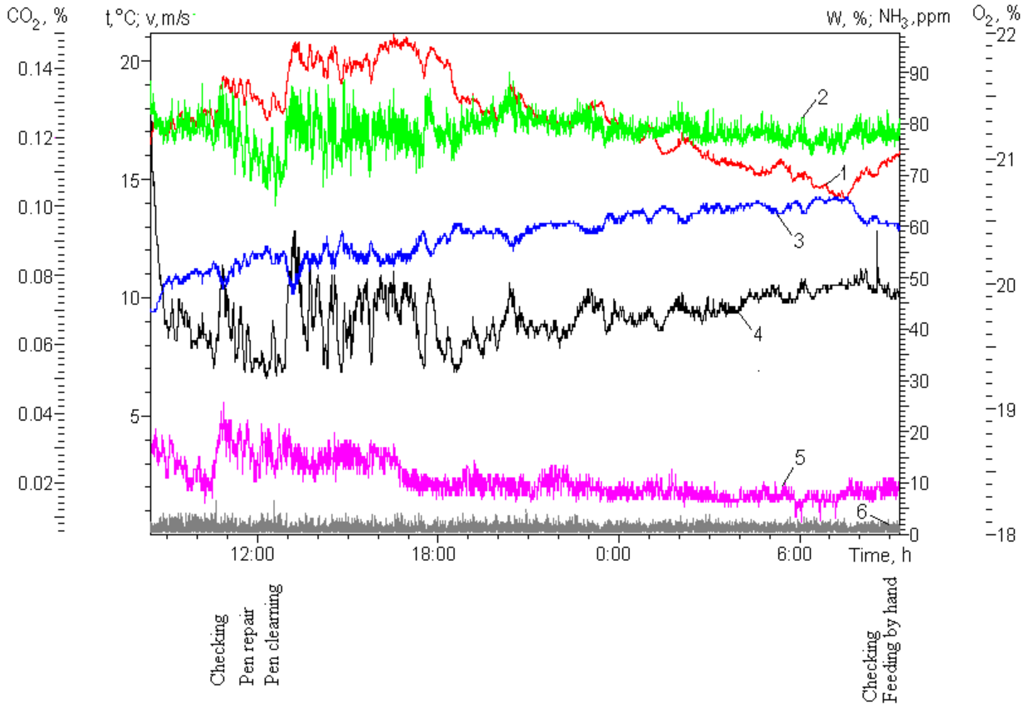


Fig. 3. Daily change of numeric values of indoor climate parameters in Pigsty B: 1– temperature, 2– relative humidity, 3– oxygen, 4– carbon dioxide, 5– ammonia, 6– air velocity.

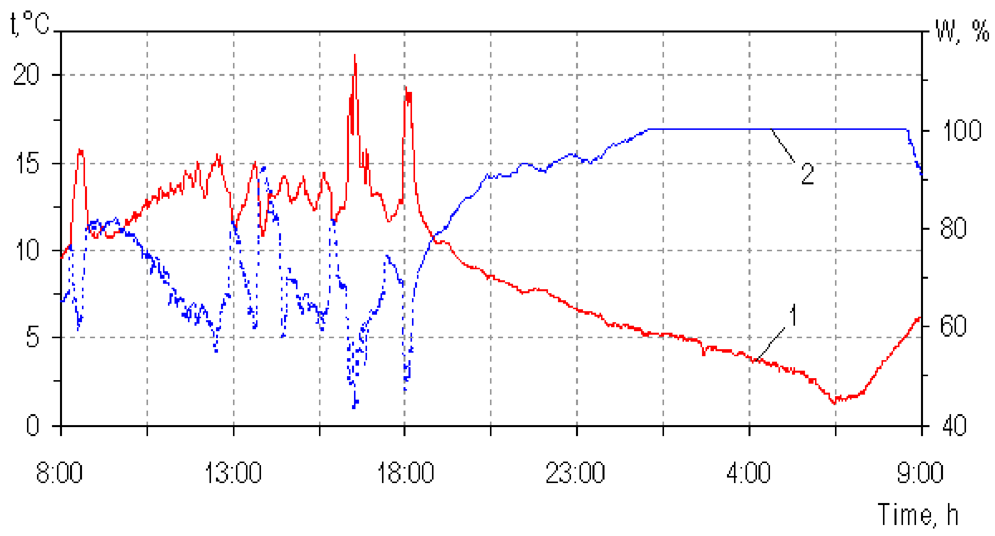


Fig. 4. Outdoor air temperature (1) and relative humidity (2) near Pigsty B.

The information also varies in the case of the highest concentration of ammonia in the air. The allowed concentration of ammonia in the air is up to 20 ppm in the European Union (CIGR, 1984). Estonian standards (http://riigiteataja.ee...73153) and authors (Tuunanen & Karhunen, 1984) refer to 20 and 25 ppm as the allowed average standard limit in the air inhaled in the human working zone. Ammonia content 6-12 cm^3/m^3 was measured in the pigsty for 220 fattening pigs (Karhunen, 1994).

Due to proper ventilation (average air velocity in Pigsty A and B was 0.17 and 0.25 $m \cdot s^{-1}$ respectively) the average ammonia content measured in the course of the study in Pigsty A (20.92 ppm) and Pigsty B (8.76 ppm) remained within the allowed standard limits (Table 2). During tending activities the content of ammonia exceeded the standard limit, and even reached 43 ppm in Pigsty A and 27 ppm in Pigsty B (Table 2; Figs 1, 3). Air emission of ammonia increased during tending activities, when pigs were awake, and moved around, treaded the manure and carried it around. Therefore it is necessary to increase ventilation in pigsties during tending activities, especially during cleaning.

According to relevant literature (Kauppinen, 2000; Reppo & Pals, 2002; Pals, 2003) elevated air temperature and moist litter in the animal-keeping premises increase the air emission of ammonia. The data provided by several authors (Mothes, 1973; Einberg, 2001; Pals, 2002; Reppo, 2002) reveal that the air emission of ammonia in the premises used for animal-keeping depends on the handling of manure, air temperature and relative humidity. It is also noted that the amounts of ammonia emitted from the manure are higher in the case of higher air temperature and higher relative humidity. The results of the 24-hour study of indoor climate carried out in deep-litter Pigsty A and Pigsty B, without litter, also reveal that a higher concentration of ammonia $P(NH_3)_t$ (ppm) was measured in the case of higher air temperature t (°C) of the pigsty (Fig. 5), and it can be calculated by using formulas (n=6,000, R^2_1=0.946; n=9,000, R^2_2=0.795), 1 and 2 respectively:

$$P_{\mathbf{A}}(NH_3)_t=0.6387 \cdot t^2-17.815 \cdot t+136.39 \quad (1)$$

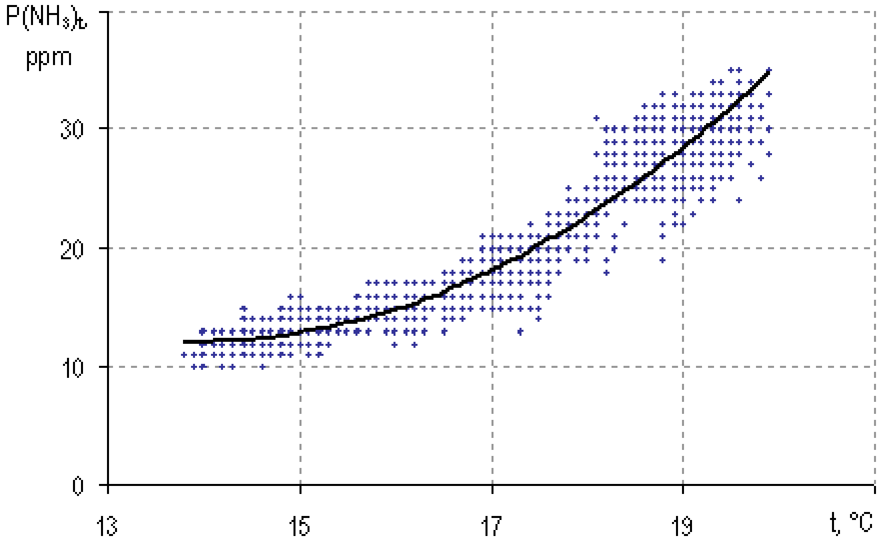
$$P_{\mathbf{B}}(NH_3)_t=0.2563 \cdot t^2-7.2362 \cdot t+55.2 \quad (2)$$

Considering that relative humidity of pigsties also depends on air temperature (Pals, 2002), this study also included determining the effect of air temperature t (°C) and relative humidity W (%) on the emission of ammonia $P(NH_3)_{tW}$ (ppm), which was expressed by formulas (n=12,000, R^2_3=0.966; n=18,000, R^2_4=0.7949) with regard to Pigsty A and Pigsty B (Fig. 6), 3 and 4 respectively:

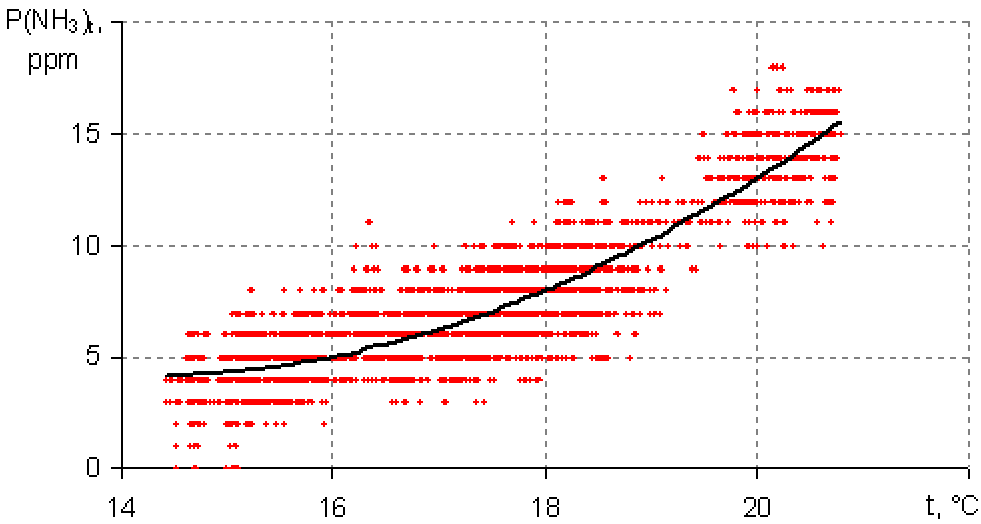
$$P_{\mathbf{A}}(NH_3)_{tW}=0.837 \cdot t^2-0.357 \cdot t \cdot W+5.649 \cdot W-195.318 \quad (3)$$

$$P_{\mathbf{B}}(NH_3)_{tW}=0.250 \cdot t^2-0.090 \cdot t \cdot W+1.569 \cdot W-69.341 \quad (4)$$

Considering the potential difference between these relationships depending on whether they are measured in summer or in winter, further studies are needed.

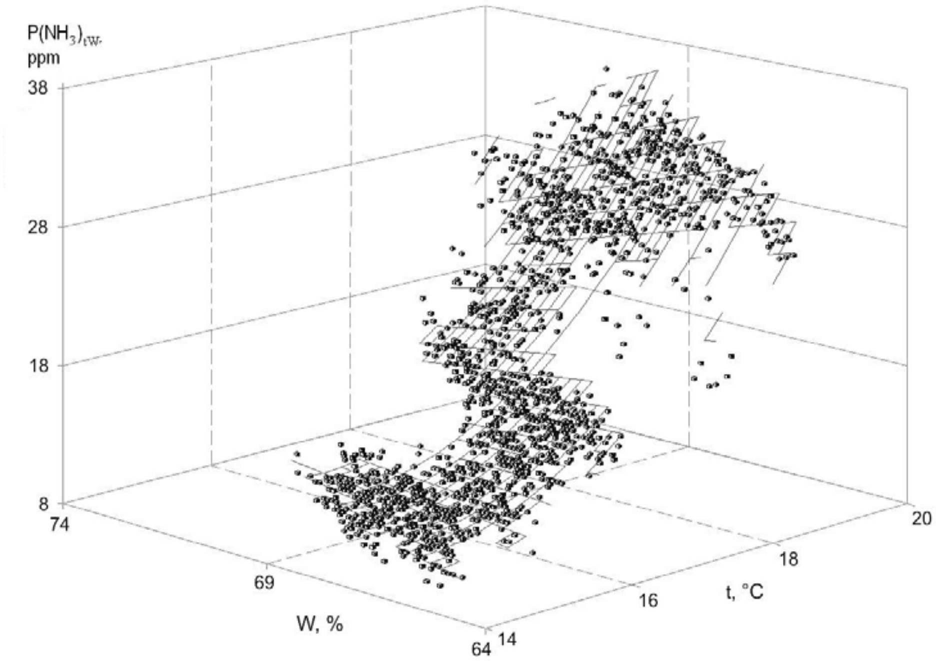


(a)

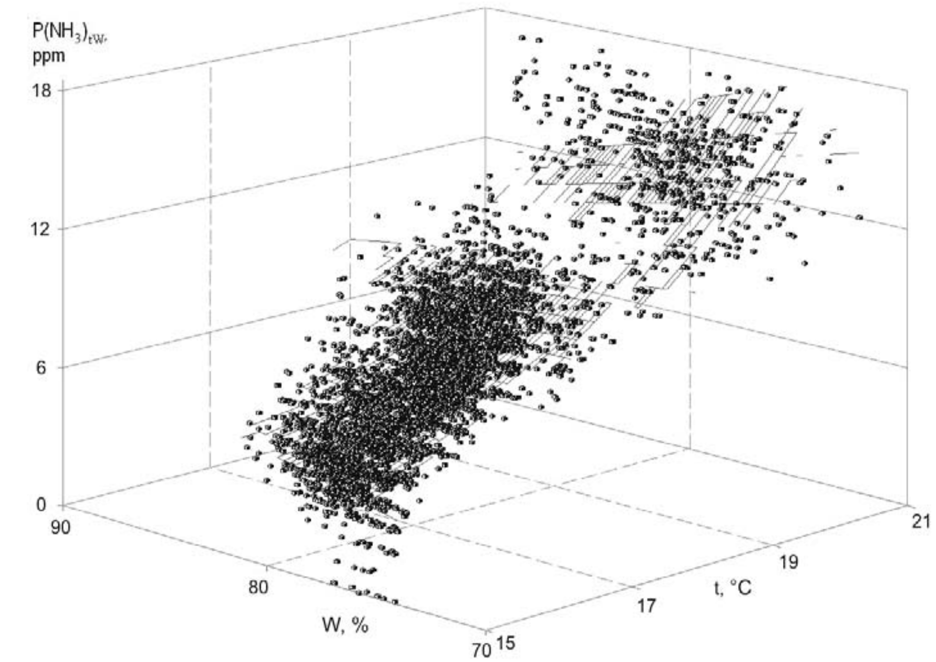


(b)

Fig. 5. Ammonia content correlation on air temperature in the Pigsties A (a) and B (b).



a)



b)

Fig. 6. Ammonia content correlation on air temperature and relative humidity in Pigsties A (a) and B (b).

CONCLUSIONS

In the course of the study, air temperature, relative humidity and air velocity, and oxygen, carbon dioxide and ammonia contents were measured during a 24-hour period in the centre of pigsties using deep litter and a liquid manure removal system at the height of 1.5 m above the pigsty in summer. Simultaneously the tending activities and animal behaviour were observed and outdoor temperature and relative humidity were measured. Data Logger equipment, relevant sensors and computer programme AMR Wincontrol were used for the study. Content of ammonia in the air was measured by using Gas Monitor Pac III equipment. Hydrolog equipment and HydroClip sensors were used for measuring the temperature and relative humidity of outdoor air and measurement results were processed by using computer programmes Pac III Software 3.nn and HW3.

Study results (Figs 1–4; Table 2) show that outdoor climate and tending activities are major factors affecting the indoor climate of the pigsties in summer. Average daily indoor temperature measured both in the deep-litter pigsty and in the pigsty without litter (17.04 and 17.60°C respectively; outdoor temperature, 18.15 and 8.75°C) and relative humidity (68.11 and 78.59% respectively; 71.88 and 84.19% in the case of outdoor relative humidity) remained within recommended limits. However, partial floor heating had to be used in the pigsty for young pigs in order to maintain optimum temperature and relative humidity of indoor air in the morning. Due to proper ventilation of the pigsties the average daily contents of carbon dioxide (0.06 and 0.07%) and ammonia (20.9 and 8.7 ppm) remained within the allowed standard limits. During tending activities the content of ammonia exceeded the allowed standard limits, reaching 43 ppm in deep-litter pigsty and 27 ppm in the pigsty without litter (Table 2; Figs 1, 3). Hence the need to increase ventilation during tending activities, especially while cleaning the pigsties.

As a result of this study the graphical and empirical relationships were determined between the concentration of ammonia and indoor temperature (Figure 5, formulas 1, 2) and between the concentration of ammonia and combined effect of the temperature and relative humidity of indoor air (Fig. 6; formulas 3, 4). Considering that these relationships may be essentially different for the indoor climate in pigsties in winter, further research is required.

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