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*Original Research*

# Impact of Animal Housing Systems on Ammonia Emission Rates

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**Abstract**

The impact of dairy cow and pig housing systems on ammonia emission rates was studied under production conditions. During research the inside and outside air temperature, relative humidity, $CO_2$ concentration in the inside and outside air and $NH_3$ concentrations in the inside air and under the slats were measured. ALMEMO, Drager Pac III, and GasProbe IAQ measuring instruments were used. From the measurement data ventilation rates and ammonia emission rates were calculated. During the housing period, the $NH_3$ emission per animal stall in an the insulated cowshed with tied cows and in a cowshed with partly slatted floor was the same at approximately 29 g per day. In an uninsulated cowshed it was less at 17 g per day. Ammonia emission during a 220-d housing period per animal stall in an uninsulated cowshed was 3.7 kg, and in an insulated shed it was 6.4 kg. The lowest emission (2.2 kg per pig per year) was achieved by keeping pigs on abundant straw litter, changed every week. With a slatted floor system, the annual ammonia emission rate was 2.5 kg per pig.

**Keywords:** ammonia emission, dairy cow, fattening pig, slatted floor, litter.

## Introduction

The potential harmful effect of ammonia emissions from livestock production was reported twenty years ago. Ammonia emission is one of the most important causes of soil and surface water acidification. More than 90% of ammonia emissions originate from agriculture [1]. High ammonia concentration is suspected to contribute to increased incidence of bronchial diseases among people engaged in indoor pig production. For many years, the improvement of environmental protection with regard to water and air pollution control has played a significant role. Until recently, only odor has been relevant for air pollution control in permit procedures with regard to intensity and hedonics. Now, gases produced by livestock farming, such as ammonia, nitrous oxide, and methane, are being increasingly considered as well [2].

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Emission from livestock buildings is 18-37% of total ammonia volatilization in animal production [3] and it is clearly important to reduce the loss from ammonia in every step of the production chain. It is known that ammonia emissions from livestock buildings depends on a number of different factors: room temperature, air speed above manure surfaces, manure temperature, floor construction, distribution of manure on the floor surface, manure removal frequency, feed composition and use of feed and manure additives [4-7]. The emission in summer is higher than that in winter. When the outdoor temperature increases by 1°C, the emission from a cow barn increases by 2.6%. The emission increases exponentially with increasing milk urea concentration [8]. In modern pig housing a large part of the pen floor is slatted, to maintain cleaner pens. Pen fouling causes extra labor for cleaning, increases the risk of health problems, and increases the emission of ammonia to the environment. However, with regard to animal welfare a clean solid floor is preferred over a slatted floor [9].

In Lithuania ammonia emissions in agriculture and industry will be limited beginning in 2010 and in subsequent years the annual limit will be 84,000 t. The most important groups of emitters in agriculture are animal husbandry and the application of mineral fertilizer. The contribution of leguminous plant cultivation is small [3]. The largest percentage of ammonia emissions from animal husbandry stems from cattle husbandry, followed by pig and poultry husbandry. It is important to implement cattle and pig husbandry systems, which emit the smallest amount of ammonia.

The objective of our work was to determine the impact of different cow and pig housing systems on ammonia emissions.

## Experimental Procedures

The experiments were carried out in three characteristic types of dairy cowsheds and in three types of pigsties with fattening pigs.

The dairy cow housing systems (Fig. 1):

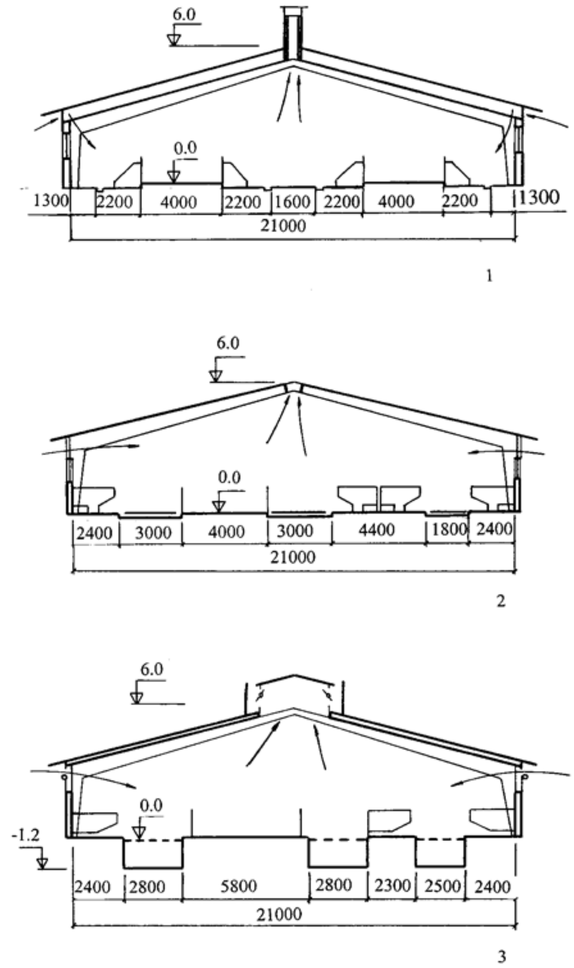


Fig. 1. The experimental cowsheds: 1 – insulated cowshed of tied cows; 2 – uninsulated cowshed with lying boxes and open manure tracks; 3 – cowshed with insulated roof, boxes and partly slatted floor.

1. Insulated cowshed of tied cows. Number of cows – 196. The manure area for one cow – 0.8 m$^2$. The coefficient of heat transmission for the roof was 0.4 W/(m$^2$ K) and one of walls – 1.0 W/(m$^2$ K). In the cowshed no litter was used. Manure from manure tracks was removed two times per day by scraper transporter. The cowshed was build in Bernatoniu village in Kaunas region.

2. Uninsulated cowshed with laying boxes and open manure tracks. Number of cows – 200. The manure area for one cow – 3.0 m$^2$. The average coefficient of heat transmission of walls and roof was 4.5 W/(m$^2$ K). The boxes were scattered with straw. Manure from the manure tracks was removed two times per day by scraper transporter. Cowshed was built in Lumpenu village in the Pagiegiu region.

3. Cowshed with insulated roof, boxes and partly slatted floor. Number of cows – 230. The manure area for one cow – 4.1 m$^2$. The coefficient of heat transmission of roof was 0.5 W/(m$^2$ K) and walls was 3.3 W/(m$^2$ K). The manure from the closed canals was removed three to four times per year. Cowshed was build in Bernatoniu village in Kaunas region.

In all cowsheds average annual yield per cow was 6000-7000 kg. The daily ratio for the cows was a mixture of maize silage, grass silage and concentrate. The weight of a cow was 500-650 kg.

The fattening pig housing systems (Fig.2):

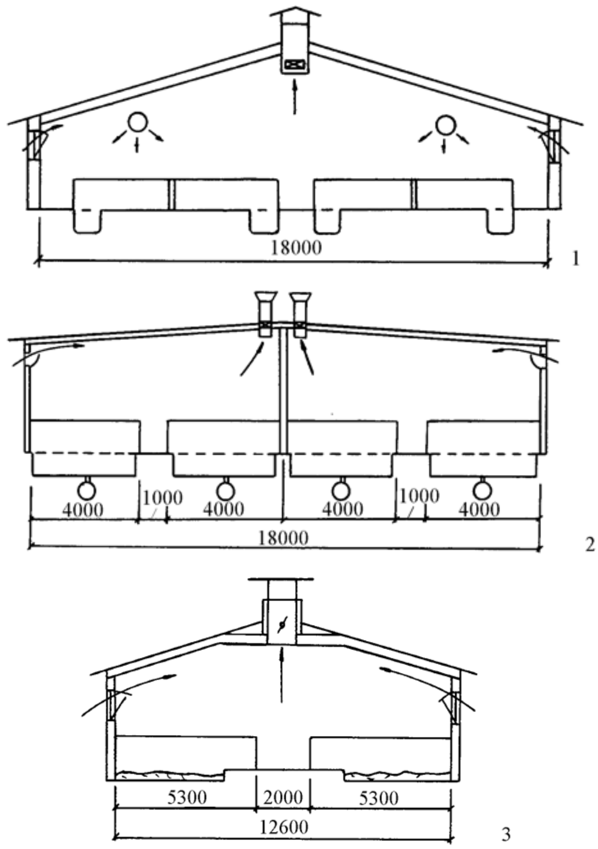


Fig. 2. The experimental pigsties: 1 – concrete floor system; 2 – slatted floor system; 3 – litter system.

1. Concrete floor system. Pigs were kept on concrete floor. For each pig there was allotted 0.9 $m^2$ of stall area and 1.2 $m^2$ of whole floor area. Every day manure from the floor surface was manually pushed into the manure canal. A mechanical ventilation and heating system was used. The pigsty was build in Berzu village in Jonavos region.
2. Slatted floor system. Pigs were kept on a slatted floor made of ferroconcrete. For each pig there was allotted 0.67 $m^2$ of stall area and 0.75 $m^2$ of whole floor area. A Big Dutchman automatic ventilation system was installed in the pigsty. The pigsty was built in Berzu village in Jonavos region.
3. Litter system. A pig stall was scattered with straw. The manure was removed every week by a tractor bulldozer. After removing the manure straw rolls were thrown into a pig pen. A 150-kg straw roll was sufficient for 11 pigs (average amount was 2 kg of straw per pig per day). A stall area for a pig was 1.4 $m^2$; the whole floor area for a pig was 1.7 $m^2$. The pigsty was naturally ventilated. The pigsty was built in Zibartoniu village in Panevezio region.

In all pigsties animals were grown from 30 kg up to 110 kg. The pigs were fed with dry feed three times a day.

All cowsheds and pigsties were oriented in a longitudinal south-north axis. Wind mainstream is from the west. Distance between cowsheds was about 30 m (20-40 m). Distance between pigsties was 20 m.

Measurement of gas emissions from livestock buildings requires reliable information on ventilation rate. One method is to equip the inlet or outlet openings with calibrated nozzles; another is to use a calibrated, free-running impeller with recording of the impeller speed as a measure of ventilation rate. Both methods are accurate, but demanding and difficult to use on site for short-term measurement, particularly where are large numbers of inlets or outlets. Therefore, it is important to use indirect methods based on easily measured parameters. For insulated buildings ventilation rates can be calculated from heat, humidity and carbon dioxide balances. For uninsulated buildings, only the carbon dioxide method is recommended [10].

In this work, the ventilation rate was calculated from a balance of carbon dioxide and humidity balance in the building [10]. During research the inside and outside air temperature, relative humidity, $CO_2$ concentration in the inside and outside air and the $NH_3$ concentration in the inside air and under the slats were measured. ALMEMO, Drager Pac III, GasProbe IAQ measuring instruments were used. From the measurement data ventilation rate and ammonia emission rate were calculated.

The investigations carried out in 2003-04. During the whole period of keeping cattle in cowsheds, in each cowshed it was measured about once a month. The measurement was carried out 1.5 m above the floor in 5 places according to both diagonals of the room: one in the middle, the other four – in 10 m distance from the end of the room. In the cowshed with partly slatted floor, the ammonia concentration was measured also under the slatted floor.

Investigations in the pigsties were carried out from January to December 2002. The measurements were made every second or third month. It was measured in 1.0 m height above the floor, at four evenly distributed places according to the area of the floor.

Ventilation rate, $m^3/s$, was calculated according to humidity balance:

$$G = \frac{e\sum Q_o}{d_i - d_o} \qquad (1)$$

Ventilation rate, $m^3/s$, was calculated according to carbon dioxide balance:

$$G = \frac{i\sum Q_o}{C_i - C_o} \qquad (2)$$

The amount of water vapour of animal and premises falling to the unit of the total heat of animals [10, 11]:

$$e = 0.15 - 7.33\times10^{-4}\,t_i + 1.733\times10^{-4}\,t_i^2 \,(0 \le t_i \le 35)^{\circ}C \qquad (3)$$

Total heat flow from cows was estimated, *W* [10]:

$$Q_0 = 5.6m^{0.75} + 1.6\times10^{-5}k^3 + 22y \qquad (4)$$

Total heat generated by pigs was estimated [12]:

$$Q_0 = 29\left(m + 2^{0.5}\right) - 40 \qquad (5)$$

The ammonia emission rate was determined as:

$$E = CG\rho\ (mg/s) = 86.4\ CG\rho\ (g/d) \qquad (6)$$

While calculating the intensity of ammonia emission the average value of ventilation intensity, which was calculated according to the equations of carbon dioxide balance and water vapour balance, was chosen.

Four to five measurements were taken in every animal shed.

Statistical methods were used for analysis of the obtained data.

## Results

Table 1 presents the results of measurements in one cowshed. It was calculated what the intensity of ammonia emission would be on the 19th of December, 2003. The air temperature of the room was 4.8°C. Then the amount of water vapour of animals and premises falling to the amount of total heat of animals (Equation 3):

$$e = 0.15 - 7.33\times10^{-4}\times4.8 + 1.733\times10^{-4}\times4.8^2 = 0.15\ \text{g/kJ}.$$

In these cowsheds, the average weight of cow was 500 kg, milk yield per day – 19 kg. Then total heat produced by one cow (Equation 4):

$$Q_o = 5.6 \times 500^{0.75} + 1.6 \times 10^{-5} \times 90^3 + 22 \times 19 = 1020 \text{ W}.$$

Total heat produced from all cows:

$$\sum Q_o = 230 \times 1020 = 234600 \text{ W} = 235 \text{ kW}.$$

Ventilation rate calculated according to humidity balance (Equation 1):

$$G = \frac{0.15 \times 235}{6.7 \times 0.92 - 3.5 \times 0.90} = 11.71 \text{ m}^3/\text{s}.$$

Ventilation rate calculated according to carbon dioxide balance (Equation 2):

$$G = \frac{51 \times 235}{1503 - 360} = 10.49 \text{ m}^3/\text{s}.$$

Average intensity of cowshed ventilation (11.72+10.49)/2 = 11.10 $m^3/s$.

The ammonia emission rate in cowshed (Equation 6)

$$E = 11 \times 11.1 \times 0.74 = 90.4 \text{ g/s}.$$

The ammonia emission rate of the stall (place) of one cow per day:

$$\frac{90.4 \times 3600 \times 24}{230 \times 100} = 34.0 \text{ g}.$$

The intensity of ammonia emission is calculated during each measurement. The summarized results of measurements and calculations in cowsheds are presented in Tables 2 and 3. Table 3 presents the results of the calculation.

There was no significant difference between $NH_3$ emission rate from animal stalls in an insulated cowshed with tied cows and a cowshed with an insulated roof and partly slatted floor. In both cowsheds, during the housing period $NH_3$ emissions from an animal unit was approximately 29 g per day. The greater area of manure in a cowshed, with partly slatted floor (4.1 $m^2$/cow in cowshed with slatted floor and 0.8 $m^2$/cow in cowshed of tied cow) stimulated greater ammonia emission, but lower temperature (7.2 and 13.6°C respecitively) reduced $NH_3$ emission. But the $NH_3$ emission in the uninsulated cowshed with boxes and open manure tracks was significantly lower than that of the insulated cowshed with tied cows, the difference was 12 g per day per cow, ($p<0.02$).

In the cowshed with a partly slatted floor ammonia concentration over the slats was 8±2 ppm, and under the slats was 11±2 ppm. The difference of about 3 ppm was not significant ($p>0.06$). Therefore, manure canals marginally increased ammonia emission.

Table 1. The measurement data in cowshed with insulated roof, boxes and partly slatted floor.

| Date | Outside air | | Inside air | | | | |
|---|---|---|---|---|---|---|---|
| | temperature, °C | relative humidity, % | temperature, °C | relative humidity, % | concentration of $CO_2$, ppm | Concentration of $NH_3$, ppm | |
| | | | | | | over slat | under slat |
| 21-11-2003 | 4.2 | 97 | 8.3 | 95 | 1050 | 13 | 18 |
| 19-12-2003 | − 4.8 | 90 | 4.8 | 92 | 1503 | 11 | 12 |
| 08-01-2004 | −11.2 | 96 | 0.4 | 96 | 2430 | 11 | 12 |
| 12-03-2004 | 0.0 | 96 | 4.9 | 79 | 650 | 3 | 5 |
| 16-04-2004 | 17.6 | 43 | 17.6 | 49 | 500 | 2 | 6 |
| Average | 1.2 | 84 | 7.2 | 82 | 1280 | 8 | 11 |

Table 2. The average climatic parameters inside air of cowsheds and outside air (variation limits), $n$ = 4-5.

| Cowshed | Outside air | | Inside air | | | |
|---|---|---|---|---|---|---|
| | temperature, °C | relative humidity, % | temperature, °C | relative humidity, % | concentration of $CO_2$, ppm | concentration of $NH_3$, ppm |
| 1. Insulated, tied cows | 4.2 (–4.8–17.6) | 80 (43–97) | 13.6 (11.2 –18.8) | 71 (52–88) | 1520 (500 –2450) | 9 (5–12) |
| 2. Uninsulated, boxes and open manure tracks | –1.0 (–5.2–5.6) | 85 (81–89) | 3.2 (–0.4 –8.2) | 82 (79–88) | 765 (480–930) | 3 (2–4) |
| 3. Insulated roof, boxes and partly slatted floor | 1.2 (–11.2–17.6) | 84 (43–97) | 7.2 (0.4 –17.6) | 82 (49–96) | 1280 (500 –2430) | 8 (2–13) |

$NH_3$ emission was fairy influenced by cowshed air temperature (Fig.3). $NH_3$ emission rate for an animal, *E*, g/d, could be expressed by the following regression equation:

$$E = 19.6 + 0.67t_i, \; R = 0.46, \; p<0.08 \qquad (7)$$

When the temperature was rising from 0°C to 15°C, the emission from an animal unit increased from 20 g to 30 g per day, i. e. 50%. However, the value of correlation coefficient is only satisfactory.

Comparative data on ammonia concentration and emission as affected by fattening pig housing system are presented in Table 4.

Pig housing system had a fair impact $p<0.3$ on $NH_3$ concentration and emission. The smallest ammonia concentration (10 ppm) and the smallest emission (6 g/d per pig) were received while keeping pigs on abundant straw litter, which was changed every week (approx. 2 kg of litter per pig per day).

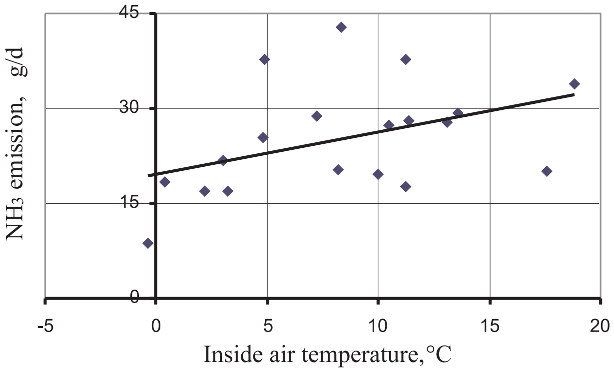


Fig. 3. $NH_3$ emission rate for an animal per day

## Discussion of Results

According to the standards of some countries, the limits of $NH_3$ emission per cow per housing period of 190-d is 8.8 kg [13], and the limit of $NH_3$ emission from a fattening pig is up to 3 kg per year, but in ecological farms it is up to 1.5 kg [14].

According to a Danish study, the average ammonia emission is 24 g/d per cow, i. e. 5.3 kg per cow per housing period of 220 d [15], and in a Hungarian study $NH_3$ emissions per year per cow were 12.2 kg (i. e. 7.4 kg per cow per housing period of 220 d) [16].

Under production conditions, ammonia emission was studied in three types of cowsheds: an insulated cowshed with tied cows, in uninsulated cowshed with laying boxes and open manure tracks, and in a cowshed with an insulated roof, boxes and partly slatted floor. During the housing period the $NH_3$ emission from an animal place in the cowshed of tied cows and in the cowshed with partly slatted floor was the same – approximately 29 g per day, and in the uninsulated cowshed it was less (17 g per day). According to the calculation the ammonia emissions during a 220-d housing period per animal unit in an uninsulated cowshed was 3.7 kg, and in an insulated one it was 6.4 kg. Ammonia emission rates did not exceed a settled standard of 8.8 kg per animal over the housing period. The ammonia emission data from experimental cowsheds corresponds well with results of other investigations.

The impact of pig housing system on ammonia emission rate was investigated in the production process. The lowest emission (2.2 kg per pig per year) was achieved while keeping pigs on abundant straw litter, which was changed every week (approx. 2 kg of litter for a pig per day). Using a slatted floor system ammonia emission rate was 2.5 kg per pig per year, and with a concrete floor sys-

Table 3. Ventilation and ammonia emission rates in cowsheds ($p<0.1$).

| Cowshed | Area of manure, $m^2$/cow | Ventilation rate per cow, $m^3$/h | $NH_3$ emission rate per cow, g/d |
|---|---|---|---|
| 1. Insulated, tied cows | 0.8 | 202 | 29±9 |
| 2. Uninsulated, boxes and open manure tracks | 3.0 | 326 | 17±6 |
| 3. Insulated roof, boxes and partly slatted floor | 4.1 | 378 | 29±9 |

Table 4. Ammonia concentration and emission applying different pig housing systems ($n=4$, $p<0.1$)

| Pig housing system | Inside air | | | $NH_3$ emission, g/d | |
|---|---|---|---|---|---|
| | temperature, °C | relative humidity % | $NH_3$ concentration, ppm | per pig | per 1 $m^2$ of stall area |
| Concrete floor system | 19 | 77 | 14±5 | 8±3 | 9±3 |
| Slatted floor system | 15 | 71 | 16±7 | 7±2 | 10±3 |
| Litter system | 17 | 74 | 10±5 | 6±2 | 4±1 |

tem it was 2.8 kg. These measured values did not exceed the official standard of 3 kg.

## Conclusions

The impact of dairy cows and pig housing systems on ammonia emission rates for every season was studied under production conditions. During research the inside and outside air temperature, relative humidity, $CO_2$ concentration in the inside and outside air and $NH_3$ concentration in inside air and under the slats were measured. ALMEMO, Deager Pac III, GasProbe IAQ measuring instruments were used. From the measurement data ventilation rate and ammonia emission rate were calculated.

The ammonia emission was studied in three types of cowsheds: an insulated cowshed with tied cows, in uninsulated cowshed with laying boxes and open manure tracks, and in a cowshed with insulated roof, boxes and partly slatted floor. During the housing period, the $NH_3$ emission from animal stall (place) in the cowshed of tied cows and in the cowshed with partly slatted floor was the same – approximately 29 g per day, and in the uninsulated cowshed, it was less (17 g per day). According to the calculation the ammonia emission during 220-d housing period per animal unit in an uninsulated cowshed was 3.7 kg, and in an insulated one it was 6.4 kg. Ammonia emission rates did not exceed a settled standard of 8.8 kg per animal over the housing period.

The ammonia emission was studied in three types of pig housing systems: concrete floor system, slatted floor system, and litter system. The lowest emission (2.2 kg per pig per year) was achieved while keeping pigs on abundant straw litter, which was changed every week (approx. 2 kg of litter per pig per day). Using a slatted floor system, ammonia emission rate was 2.5 per pig per year, and with a concrete floor system it was 2.8 kg. These measured values did not exceed the official standard (of 3 kg).

## Units and Nomenclature

C – ammonia concentration in the inside air, ppm
$C_i$, $C_o$ – $CO_2$ concentration in inside and outside air, ppm
$d_i$, $d_o$ – amount of water vapour in a unit of inside and outside air volume, g/m$^3$
e – amount of water vapour of animals and premises falling to the unit of the total heat of animals, g/kJ
G – ventilation rate, m$^3$/s
E – ammonia emission rate, mg/s and (g/d)
i – $CO_2$ production on animals falling to the unit of the total heat of animals, cm$^3$/kJ (51 cm$^3$/kJ)
k – days of pregnancy
m – body mass, kg
$t_i$ – inside air temperature, °C
$Q_o$ – total heat produced by one animal, W
$\sum Q_o$ – total heat produced by all animals, kW
y – milk production, kg/d
ρ – density of ammonia, mg/cm$^3$ (0.74 mg/cm$^3$)

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