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EMISSION OF WATER VAPOUR IN UNINSULATED COWSHED

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Abstract

The aims of this study were, first, to work out a simple method to establish water vapour emission in a cattle house under production conditions, and then to establish the emission of water vapour in an uninsulated cowshed during the winter. It was analytically found that to determine water vapour emission in a room it is enough to measure the indoor and outdoor temperature, relative humidity and carbon dioxide concentration in the indoor and outdoor air. After an uninsulated cowshed was studied, a regression equation (exponential) relating the flow of water vapour emission with the indoor air temperature was drawn. When temperature is –10°C, specific intensity of water vapour emission (amount of water vapour produced by animals and the room per unit of total animal heat) is 0.054 g/kJ and at +10°C it is 0.135 g/kJ. When using the values of specific water vapour emission, the calculation of parameters of ventilation intensity and ventilation system becomes simplified.

Key words: cows, sheds, water, emission, air temperature.

Today's livestock and poultry production systems require better control of the thermal environment for animals to reach their genetic potential in growth and feed efficiency (Hoff, 2004). The ventilation and outside partitions are a necessity for all controlled climate animal shed. When designing a barn ventilation system and outside partitions important criteria are flows of animal heat and water vapour. Water vapour is produced by animals breathing and sweating. It also evaporates from excrements, water-troughs and from feeding troughs when moist or liquid feed is used. The intensity of water vapour depends on species of animals, temperature of the indoor air and animal husbandry technologies.

There is data in scientific and standard literature on the amount of water vapour produced by animals and the room. Data on water vapour production from dairy and feedlot cows available in the literature are primarily based on studies made in the late 1950s (Yeck and Stewart, 1959). Comprehensive research in water vapour emission in cattle houses and pigsties under natural production conditions was carried out

30 years ago (Jurgenson, 1976). The barns were insulated, the indoor temperature was above zero. The cattle were kept in a tied-up system. Comprehensive standard data on the amount of water vapour produced was presented (Albright, 1990). The amounts of water vapour breathed out by an animal and emitted by excrements are given separately. The latter source of water vapour accounts for 13% of the water vapour amount breathed out by an animal. However, the results are given for a situation when the animals are kept in the temperature above –1°C. An in-depth analysis of different research results on the flows of total, sensible and latent heat of the animal, which are directly related with the emission of water vapour were carried out by Pedersen et al. (1998). According to the generalized data the humidity emitted in cattle houses reduces the flow of sensible heat by 10–20%, i.e. the humidity produced in the house accounts for 10–20% of the amount of water vapour produced by animals breathing and sweating. This data is typical of warm barns in which air temperature ranges from 0 to 35°C. In recent years sweating rates from heat-stressed dairy cows and beef heifers were measured using a "Portable calorimeter" and "Bovine evaporation meter". The focus of the study was to compare sweating rates measured from different breeds of dairy cows and beef heifers, and determine the level of influence of environmental factors (air temperature, relative humidity, solar load, and air velocity) and hair-coat colour on sweating rate. Sweating rates were found to range between 189±84.6 and 522±127 g m^{-2} h^{-1} (Gebremedhin et al., 2008).

In recent decades cow productivity has increased and conditions of their housing have changed. The recommended temperature of 10–20°C in 1969 decreased considerably as it was proved that a productive cow emitting large amounts of heat was protected by low temperature from overheating. It was established (Epinatjeff, 1997) that the most appropriate temperature for a cow yielding 20 or more kilograms of milk per day was from +5°C to –10°C. The yields decrease considerably only when temperature exceeds +24°C and drops down to –7°C and lower.

Intensive construction of uninsulated cowsheds started in 1985 in Western Europe, in 1990 in Scandinavian countries, in 1995 in Estonia and in 1999 in Lithuania. Research results of different authors give different data regarding the average temperature in uninsulated cowsheds during the coldest season, namely: –7.5°C (outdoor temperature –14.7°C) (Mikson and Reppo, 2006) and –10.2°C (outdoor temperature –15.0°C) (Kavolelis and Bleizgys, 2006).

The amount of heat and water vapour produced by animals is established by using a calorimeter (Chepete and Xin, 2001; Gebremedhin et al., 2008) or directly in a room where animals are housed (Jurgenson, 1976). The first method provides a more accurate measurement of heat and water vapour produced by an animal and the second method measures the amount of water vapour emitted in the room. But both methods require reliable information on ventilation rate.

The objectives of this study were: first to work out a simple method to establish water vapour emission in a cattle house under production conditions, and then to establish the emission of water vapour in an uninsulated cowshed during the winter.

Material and methods

Good agreement was found between heat, water vapour and carbon dioxide balances (Teye and Hautala, 2007). The majority of researchers have established that CO_2 emission production in animal housing premises is directly proportional to the total heat production of animals and on average it is 0.185 m^3/kWh (Blanes and Pedersen, 2005), i.e. 51 cm^3/kJ. There are works proving that the amount of water vapour produced by animals and the room is also proportional to the amount of the total animal heat (Jurgenson, 1976). This is also proved by the analysis of standard data (Albright, 1990). Therefore, in this work it is accepted that water vapour production is proportional to animal total heat production, i.e.

$$\Sigma W = e\Sigma Q_o \quad \textbf{(1)}$$

where

ΣW – total water vapour flow produced by animals and room (g /s),

e – specific intensity of water vapour emission (amount of water vapour produced by animals and room per animal total heat unit) (g /kJ),

ΣQ_o – total heat of the cattle flow rate (kW).

Intensity of room ventilation G (m^3/s) can be expressed by water vapour balance

$$G = \frac{e\Sigma Q_o}{d_i\varphi_i - d_o\varphi_o} \quad \textbf{(2)}$$

Or by balance of carbon dioxide

$$G = \frac{i\Sigma Q_o}{C_i - C_o} \quad \textbf{(3)}$$

where

d_i – maximum content of water vapour in the indoor air (g/m^3),

d_o – maximum content of water vapour in the outdoor air (g/m^3),

φ_i – indoor air relative humidity (parts of unit),

φ_o – outdoor air relative humidity (parts of unit),

i – specific intensity of CO_2 emission (amount of CO_2 per animal total heat unit (cm^3/kJ) (51 cm^3/kJ)),

C_i – carbon dioxide concentration in the indoor air (ppm),

C_o – carbon dioxide concentration in the outdoor air (ppm).

Having solved (2) and (3) equation is drawn

$$e = \frac{51\,(d_i\varphi_i - d_o\varphi_o)}{C_i - C_o} \quad \textbf{(4)}$$

It can be seen from equation (4) that in order to find the value of water vapour emission in a room it is enough to measure the indoor and outdoor temperature, relative humidity and carbon dioxide concentration in the indoor and outdoor air.

The research was made in an uninsulated cowshed with boxes. The boxes were covered with rubber mats without bedding. The floor of walking alleys was made of concrete. Manure is removed by a cable scrapper. The average mass of a cow was about 600 kg; the daily milk yield was about 19 kg. The main feed of the cows was maize silage. The cowshed was 22 m wide and 72 m long. The capacity was 200 cows. The average heat transfer coefficient of walls was 4.5 (W m^{-2} K^{-1}) and that of roof – 5.0 (W m^{-2} K^{-1}).

During the study the indoor and outdoor temperature and relative humidity were measured as well as CO_2 concentration in the indoor and outdoor air. According to the measured values specific water vapour emission was calculated.

Indoor air parameters were measured 1.5 m above the floor surface, in 5 spots according to the room's diagonals: one in the middle and the other four at a 10 m distance from the room's ends. Each measurement was repeated 3–5 times. Measurements were made when the intensity of ventilation was steady, i.e., at least one hour after the door was shut. The research was made during winter.

Air temperature and relative humidity were measured by ALMEMO device, and CO_2 concentration by Gas Probe IAQ device.

The correlation regression analysis of the final results was made.

Results

The mean values of the indoor and outdoor air climatic indicators and calculated values of specific emission rate of water vapour intensity are presented in Table 1. The total number of test variants is 14. During the research the outdoor air temperature varied from +4.8 to –17.2°C and the indoor air temperature varied from +11.2 to –10.8°C. In the latter case the manure in walking alleys was frozen. Water-troughs were functioning in the ordinary way.

Table 1. Climatic parameters and specific emission rate of water vapour e ($P \leq 0.05$)

Test variant	Outdoor			Indoor			*e* (g/kJ)
	t_o (°C)	φ_o (%)	C_o (ppm)	t_i (°C)	φ_i (%)	Ci (ppm)	
1	–5.0±1.1	98±4	360±10	0.0±0.3	96±3	1290±80	0.075
2	4.1±1.2	97±3	360±10	8.2±0.8	95±2	1050±80	0.128
3	–4.8±1.0	90±3	360±10	4.8±0.4	92±2	1770±130	0.112
4	–0.1±0.3	94±2	360±10	5.2±0.6	91±1	1080±80	0.121
5	4.8±0.2	80±3	380±10	11.2±1.2	73±2	1040±70	0.150
6	–16.0±0.4	86 ±3	360±10	-9.4±0.3	86±1	1030±60	0.060
7	-11.3±0,5	70±2	350±10	-0.5±0.2	72±2	1500±80	0.084
8	–9.8±0.4	65±1	400±20	-3.0±0.4	62±3	1050±130	0.070
9	–10.0±0.6	66±2	400±20	-2.7±0.5	80±4	1450±130	0.081
10	–8.5±0.5	61±1	390±20	-2.7±0.6	68 ±2	1130±120	0.078
11	3.0±0.5	88±3	390±20	7.0±0.7	86±5	1070±120	0.100
12	–16.5±0.4	87±2	370±10	–10.1±0.8	86±2	1080±110	0.055
13	–17.0±0.5	89±3	360±10	–10.3±0.5	87±3	1060±110	0.053
14	–17.2±0.4	86±3	380±10	–10.8±0.5	85±2	1070±110	0.050

t_o, t_i, – outdoor and indoor air temperature; φ_o, φ_i – outdoor and indoor air relative humidity; C_o, C_i – CO_2 concentration in outdoor and indoor air.

The analysis of the results suggests that the greatest influence on the specific emission rate of water vapour intensity is made by the indoor air temperature (Figure 1). The following exponential equation was achieved

$$e = 0.085 \times 10^{0.02t_i} \quad \textbf{(5)}$$

where

t_i – indoor air temperature (°C).

Correlation coefficient R= 0.94, its reliability – 8.3.

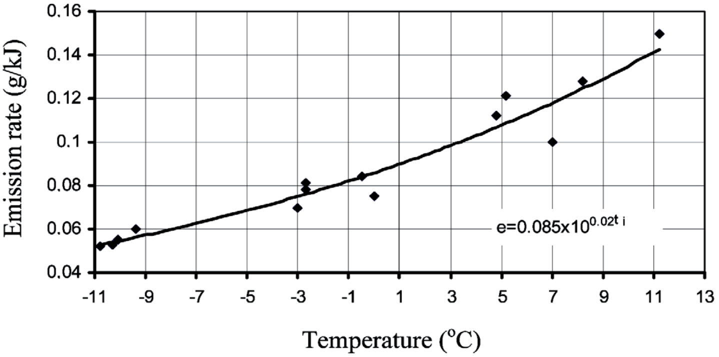

Figure 1. The dependence of specific emission rate of water vapour on indoor temperature

Discussion

A simple method to establish water vapour emission in a cowshed was substantiated. By using this method under the conditions of natural function in the stall cowshed, it was established how water vapour emission depended on the indoor air temperature; when it varies from –10.8°C to +11.2°C, this dependency is expressed as an exponential.

When comparing the results with the data of other authors obtained at above-zero temperatures, it can be stated that the results obtained within the range of above-zero temperatures reliably coincide with the data of other authors (Jurgenson, 1976) obtained under production conditions. The comparison of the results obtained with the data reported by other authors and standard data is presented in Figure 2.

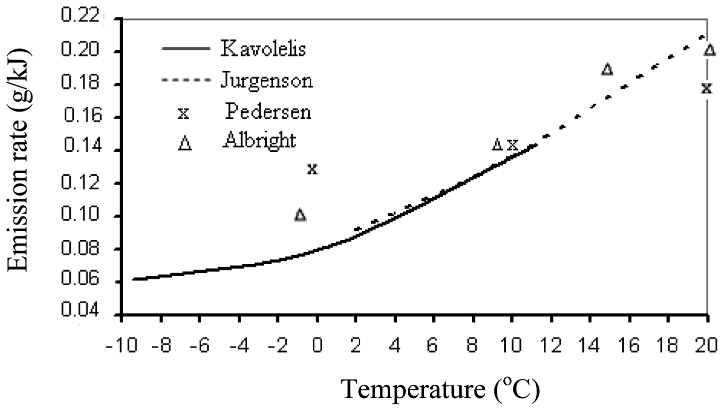

Figure 2. Dependence of specific emission rate of water vapour on indoor temperature as measured and reported by three studies (Jurgenson, 1976; Pedersen, 1998; Albright, standard data 1990)

According to the data of Pedersen et al. (1998), when cattle are fed with the feeds in which dry matter accounts for more than 30% and the floor is damp, the calculated specific values of water vapour emission, when the indoor temperature is 0°C, are 1.5 times higher than the results achieved. However, as the air temperature rises this difference decreases down to an insignificant one. According to the standard data (Albright, 1990) the calculated values differ from the results obtained even less and at 0°C air temperature this difference equals 20%. As the temperature rises the difference also decreases down to an insignificant one.

It can be stated that the regression equation drawn describes the process of water vapour emission in a cowshed rather accurately both within above-zero and below-zero temperature range.

When e value is known, it is possible to calculate ratio ε of sensible and total animal heat which assesses the humidity produced by animals and the room

$$\varepsilon = 1 - 2.5e \quad \textbf{(6)}$$

where:
2.5 – specific heat of water vapour (kJ/g).

When the ratio of sensible and total animal heat is known, the necessary ventilation intensity and the ventilation system parameters can be calculated, i.e.

$$G = \frac{\sum Q_o}{c}\left[\frac{\varepsilon + x\,\eta I}{\Delta t} - x_o\right] = \rho_o v_1 A_1 = \rho_i v_2 A_2 \quad \textbf{(7)}$$

where:

G – intensity of necessary room ventilation (kg/ s),

c – specific heat capacity of air (kJ kg^{-1} K^{-1}),

x_o – total module of heat losses through building partitions (walls, roof, floor and foundations) (K^{-1}),

x – partial module of heat losses through building walls and roof (K^{-1}),

η – coefficient that evaluates solar irradiance (m^{2}K/W) (about 0.022 m^{2}K/W),

I – density of sun energy flow towards the building surface (W/m^2),

D_t – permissible difference between indoor and outdoor air temperature (°C),

ri – indoor air density (kg/m^3),

ro – outdoor air density (kg/m^3),

v_1 – air speed in inlets (m/s),

v_2 – air speed in outlets (m/s),

A_1 – total areas of air inlets (m^2),

A_2 – total areas of air outlets (m^2).

Total heat loss module:

$$x_o = \frac{\sum UA + \psi P}{\sum Q_o} \quad \textbf{(8)}$$

Partial heat loss module:

$$x = \frac{\sum UA}{\sum Q_o} \quad \textbf{(9)}$$

where:

U – heat transfer coefficient of partitions (walls and roof) (W m^{-2} K^{-1}),

A – partition area (m^2),

y – specific heat losses through floors and foundations (W m^{-1} K^{-1}),

P – perimeter of foundations (m).

When foundations and floors are insulated, the specific heat losses through floors and foundations y = 0.9, and when they are uninsulated – y = 1.5 (W m^{-1} K^{-1}) (Albright, 1990).

For uninsulated barns to avoid condensation of water vapour on the internal side of the outer partitions the permissible difference of the indoor and outdoor temperatures are as follows (Kavolelis and Sateikis, 2004):

$$\Delta t = -\frac{260}{U} - lg\varphi_1 \quad \textbf{(10)}$$

where:

U – heat transfer coefficient of a partition on which water vapour condensation is not allowed (Wm^{-2} K^{-1}).

The following conclusions were drawn:

– The literature analysis suggests that there is no data on water vapour emission in a cowshed with below-zero temperature.

– A method to determine water vapour emission in a barn was substantiated.

– The research was carried out in an uninsulated cowshed and a regression equation relating water vapour emission with the inside air temperature was drawn.

– Having compared research results with the results by other researchers obtained in insulated cowsheds, it can be stated that the exponential equation relating the values of specific water vapour emission with the indoor air temperature reflects well the process of water vapour emission in a cowshed.

– When using the values of specific water vapour emission the calculation of parameters of ventilation intensity and ventilation system becomes simplified.

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Emisja pary wodnej w nieocieplonej oborze

STRESZCZENIE

Celem badania było opracowanie prostej metody określania emisji pary wodnej w budynku dla bydła w warunkach produkcyjnych, a następnie określenie emisji pary wodnej w nieocieplonej oborze w okresie zimowym. Analizy wykazały, że do określenia emisji pary wodnej w pomieszczeniu wystarczają pomiary temperatury wewnętrznej i zewnętrznej, wilgotności względnej i stężenia dwutlenku węgla w powietrzu wewnętrznym i zewnętrznym. Po zbadaniu nieocieplonej obory wyprowadzono wykładnicze równanie regresji określające zależność między przepływem pary wodnej a temperaturą powietrza w pomieszczeniu. Właściwe natężenie emisji pary wodnej (ilość pary wodnej wytworzonej przez zwierzęta i pomieszczenie na jednostkę całkowitego ciepła wydzielanego przez zwierzę) wynosi 0,054 g/kJ przy temperaturze –10°C i 0,135 g/kJ przy temperaturze +10°C. Korzystając z wartości właściwej emisji pary wodnej, można uprościć obliczenie parametrów natężenia wentylacji i systemu wentylacji.