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Method for determining the ventilation air quantity in buildings for cattle on a base of CO_2 concentration

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Summary. Quantity of the ventilation air stream in buildings for cattle can be determined by means of constant concentration of an indicator gas, which requires sophisticated devices for data acquisition. Carbon dioxide emitted by animals may play a function of the indicator gas. The paper presents the method for calculating the ventilation air stream amount in livestock buildings equipped with natural ventilation system. The stream amount can be determined on the basis of measured concentration of the carbon dioxide and air temperature in animal compartment applying the worked out equations. The calculations take into account the livestock density and cow's dairy efficiency.

Key words: livestock building, natural ventilation, air stream, calculation method.

List of symbols:
C – concentration of gas in the air, mg/m^3
C_{CO2} – concentration of carbon dioxide in the air, mg/m^3
hpu – heat production unit equal to 1000 W of the total heat at temperature 20^{o}C,
m – weight of animals, kg
M – molecular weight, g/mol
n – number of cows in herd, animals
p – pregnancy duration, days
t_w – temperature of internal air, ^{o}C
$\dot{V}$ – amount of ventilation air, m^3/s
V_v – molar volume, dm^3/mol
Y_1 – daily dairy production, kg
Φ_{zc} – total heat emitted by animals, W $\Phi_{zc}(t_w)$ – total heat emitted by animals at the ambient temperature equal to t_w, W

INTRODUCTION

There are different solutions of ventilation systems in livestock buildings depending on required quantity of ventilation air stream, which depends in turn on type of livestock in the building. The main task of the ventilation system consists in removing the harmful gases excess and maintaining the optimum air temperatures in animal compartments [2,7,9,12]. Mechanical ventilation is applied in buildings for poultry due to great needs for air exchange and necessity to avoid excessive dusting, which in consequence could lead to explosive gas mixture formation [8].

Cattle buildings can be equipped with various constructional and functional solutions as well as various devices depending on the herd size and animal husbandry technology [6,15,16,17]. Ensuring the appropriate ventilation in animal compartment is a fundamental condition for maintaining the animal's welfare and high dairy production [3,4,5,13]. Buildings for cattle are most often equipped with natural ventilation system, while chimney ventilation is applied in buildings with relatively small livestock density and utility garret, and natural ventilation with ridge gap is useful in hall-type buildings with no garret. The quantity of ventilation stream depends on a spectrum of factors such as geometric dimensions of the system elements, the air pressure difference between the inlet and outlet, velocity, and direction of winds, as well as air flow resistance (drag) [18]. There is a possibility to some regulation of the stream intensity by means of partial closing the supply or exhaust ventilation holes, which results from different needs for air exchange in summer and in winter.

THE AIM OF STUDY

It is possible to determine the true amount of ventilation stream in a livestock building by means of measuring the air flow velocity in a supply or exhaust channel (gap). Mounting the anemometer, particularly in the ridge gap that is placed several meters up, is sometimes difficult, and adjusting the measurement unit perpendicularly to the air flow direction is often completely impossible.

There are also a variety of factors that make such measurement disturbed and result precision biased: strength and direction of winds, uncontrolled air exchange due to doors and windows opening.

The study aimed at presenting the method for determining the quantity of ventilation air stream in buildings for cattle on the basis of carbon dioxide concentration in animal compartment.

CARBON DIOXIDE CONCENTRATION IN ANIMAL COMPARTMENT

Studies upon microclimate parameters in stanchion barns for cattle indicate that carbon dioxide concentration usually does not exceed the permissible level [14]. This was confirmed by research performed in loose barn localized in Ossowa. Measurements of carbon dioxide concentration and air temperature within animal compartment as well as outer air temperature, were made in winter 2008. The measurement device was set up to measure and register the results at 15-minute intervals. Carbon dioxide concentration oscillated within quite wide range from 400 up to 1500 ppm (Figure 1), whilst it did not exceed the maximum value (3000 ppm). Such large differences in CO_2 concentrations were not the result of the variations in animal's emission, because livestock density was constant. It rather resulted from the changes in the intensity of natural ventilation system operation. The quantity of ventilation air stream varies with time and along with the change of pressure difference between the supply and exhaust. The air pressure difference depends on the height difference (that is constant) and difference between internal and external air temperatures (that varies with time). Dependence of CO_2 concentration in the air in animal compartment is presented on plots (Figure 2).

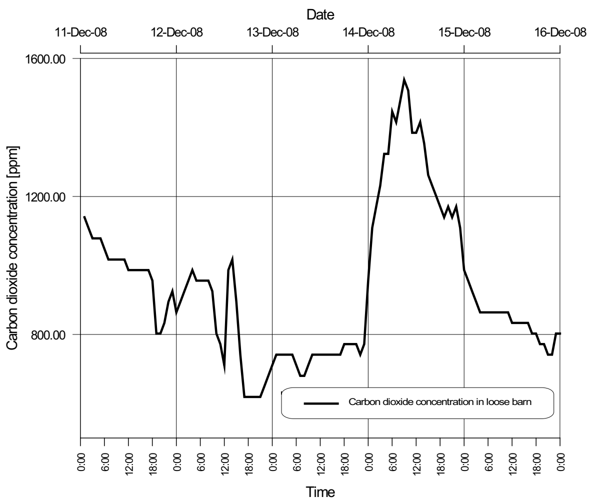

Fig. 1. Carbon dioxide concentration in loose barn.

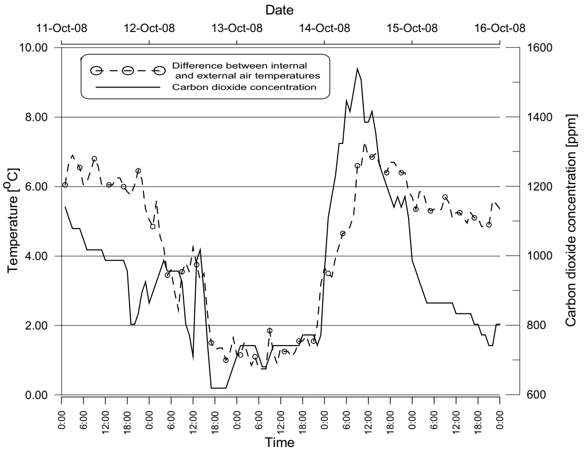

Fig. 2. Carbon dioxide concentration and difference between internal and external air temperatures.

METHOD FOR DETERMINING THE VENTILATION AIR STREAM QUANTITY

There are methods for determining the exchanged air stream in a building due to ventilation and infiltration [1]. These are three methods applying the marker gas:

- Marker gas decline method,
- Constant injection method,
- Constant concentration method.

Four types of the marker gas are suitable for measurements of the multiplicity of air exchange: helium, sulfur hexafluoride, nitrogen oxide, and carbon dioxide. However, carbon dioxide cannot be used if the user is present within the measurement zone, because he emits CO_2 as well [PN-EN ISO [22]]. If it is assumed that the livestock density in analyzed period is constant and carbon dioxide emission does not change with time, the carbon dioxide emitted by animals can be considered as the marker gas. In fact, the CO_2 emission depends on animal's activity and ranges within a day [19]. The quantity of carbon dioxide emitted by animals is strictly associated with the amount of heat released. Amount of the total heat produced by dairy cows at the ambient temperature (20 °C) [20,21] equals to:

$$\Phi_{zc} = 5,6m^{0,75} + 22Y_1 + 1,6 \cdot 10^{-5} p^3 \quad \text{W}, \tag{1}$$

Assuming that dairy cattle herd in an animal compartment consists of *n* animals, mean b&w cow's body weight is 600 kg, and average degree of cow's pregnancy advance is 100 days [Głuski 2009], equation #1 can be written in the following form:

$$\Phi_{zc} = n \cdot (694,9 + 22Y_1) \quad \text{W}, \tag{2}$$

The outer temperature other than 20 °C is taken into account in reference to hpu unit:

$$\Phi_{zc} = 1000 + 4 \cdot (20 - t_w) \quad \text{W}, \tag{3}$$

Therefore, the amount of the total heat in the animal compartment t_w produced by cattle herd consisting of n cows is:

$$\Phi_{zc}(t_w) = n \cdot (694,9 + 22Y_1)\left[1 + \frac{4(20 - t_w)}{1000}\right] \quad \text{W}, \qquad (4)$$

And in more simple form:

$$\Phi_{zc}(t_w) = n \cdot (694,9 + 22Y_1)(1,08 - 0,004t_w) \quad \text{W}, \qquad (5)$$

The quantity of produced CO_2 amounts to 0.185 m^3h^{-1} in reference to a single *hpu* unit. The dairy cattle herd consisting of n animals at the ambient temperature of t_w would emit the following quantity of carbon dioxide per hour:

$$CO_2(t_w) = n \cdot 0,185 \cdot 10^{-3}(694,9 + 22Y_1)(1,08 - 0,004t_w) \quad m^3h^{-1}. \qquad (6)$$

Carbon dioxide is one of the air components and its proportion in clean air is 360 ppm (706.8 mg/m^3). Permissible CO_2 level in an animal compartment, where dairy cattle is kept, amounts to 3000 ppm (5890 mg/m^3). The CO_2 concentration in air, as similar as other harmful gases, is measured and expressed in ppm units (parts per million). In order to recalculate the gas concentration from ppm onto mg/m^3, following dependence can be applied [11]:

$$C = \frac{M}{V_v} \cdot x \cdot ppm \quad \text{mg/m}^3. \qquad (7)$$

Molecular weight of carbon dioxide is 44.01 g/mol, and molar volume is constant for all gases and equals to 22,415 dm^3/mol:

$$C_{CO_2} = \frac{44,01}{22,415} \cdot x \cdot ppm = 1,963 \cdot x \cdot ppm \quad \text{mg/m}^3. \qquad (8)$$

Carbon dioxide emitted by animals is removed out of the animal compartment by ventilation system. Volume of 1 m^3 of internal air, in which measured carbon dioxide concentration is x ppm, contains x 10^{-6} m^3 CO_2, whereas 1 m^3 of the outer air contains CO_2 quantity corresponding to 360 ppm, i.e. 0.00036 m^3. Exchanging 1 m^3 of air per hour by means of ventilation, the difference of carbon dioxide between inner and outer air is removed. Because the whole herd emits during an hour the carbon dioxide described by equation #6, the stream of ventilation air V m^3h^{-1} at the moment of CO_2 concentration measurement in internal air, amounts to:

$$V = \frac{CO_2(t_w)}{(x - 360) \cdot 10^{-6}} = \frac{n \cdot 0,185 \cdot 10^{-3}(694,9 + 22Y_1)(1,08 - 0,004t_w)}{(x - 360) \cdot 10^{-6}} \quad m^3h^{-1}, \qquad (9)$$

After simplifications, equation #9 is of the following form:

$$V = \frac{n \cdot 185 \cdot (694,9 + 22Y_1)(1,08 - 0,004t_w)}{(x - 360)} \quad m^3h^{-1}, \qquad (10)$$

CONCLUSIONS

The method worked out during this research makes it possible to determine the quantity of ventilation air stream in buildings for dairy cattle equipped with gravitational ventilation system. The method does not require any sophisticated devices for data acquisition. The procedure for determining the amount of ventilation air stream consists of the following steps:

1. Making the measurements of carbon dioxide concentration and air temperature within animal compartment,
2. Determining the livestock density,
3. Determining the average dairy efficiency in a herd,
4. Calculating the ventilation air stream.

REFERENCES

1. **Baranowski A. 2007.** Modelowanie wentylacji naturalnej budynków wielorodzinnych. Zeszyty Naukowe. Inżynieria Środowiska/Politechnika Śląska. 55.
2. **Buczaj M., Sumorek A. 2011.** The use of labview environment for the building of supervision system controlling the climatic and technical parameters in farm rooms. TEKA Kom. Mot. Energ. Roln. – OL PAN, 2011, 11, 18-28.
3. **Chodanowicz B., Woliński J., Wolińska J. 2009a.** Problemy chowu bydła w oborach bez izolacji termicznej. Inżynieria Rolnicza. Nr 5. (114). 49-53.
4. **Chodanowicz B., Woliński J., Wolińska J. 2009b.** Wentylacja w oborach bez izolacji termicznej. Inżynieria Rolnicza. Nr 6. (115). 17-21.
5. **Daniel Z. 2008.** Wpływ mikroklimatu obory na mleczność krów. Inżynieria Rolnicza. Nr 9. (107). 67-73.
6. **Horyński M. 2008.** Heating system control in an inteligent building. TEKA Kom. Mot. Energ. Roln. – OL PAN, 2008, 8, 83-88.
7. **Głuski T. 2003.** Temperatury obliczeniowe w klasycznej metodzie bilansowania ciepła w budynkach inwentarskich. Inżynieria Rolnicza 9(51). 325-333.
8. **Głuski T., Siarkowski Z. 2003.** Wyposażenie techniczne ferm drobiarskich a zagrożenie pożarowe. Motorol. Motoryzacja i energetyka rolnictwa. Tom 5.
9. **Głuski T. 2005.** System kształtowania mikroklimatu w budynkach dla bydła. Rozprawy Naukowe Akademii Rolniczej w Lublinie, WAR w Lublinie, zeszyt 291, PL ISSN 0860-4355.
10. **Głuski T. 2009.** Parametry stada w procesie projektowania mikroklimatu w budynkach dla bydła. Inżynieria Rolnicza 6(115).
11. **Godish T. 2003.** Air Quality. Lewis Publishers. ISBN: 978-1-56670-586-8.
12. **Külling D., Menzi H., Kröber T., Neftel A., Sutter F., Lischer P., Kreuzer M. 2001.** Emission of ammonia, nitrous oxide and methane from different types of dairy manure during storage as affected by dietary protein content. J. Agric. Sci. 137: 235-250.
13. **Malaga-Toboła U. 2011.** Operating costs of farm buildings in selected ecological holdings. TEKA Kom. Mot. i Energ. Roln. – OL PAN, 11c, 181-190.

14. **Marciniak A.M., Romaniuk W., Tomza A. 2005.** Wpływ systemu chowu na koncentrację zanieczyszczeń gazowych (NH3, CO2, H2S) w oborach wolnostanowiskowych. Problemy Inżynierii Rolniczej Nr 4/2005.
15. **Marczuk A. 2009.** System ekspertowy wyboru technologii utrzymania zwierząt dla producentów bydła. Inżynieria Rolnicza. Nr 6 (115). 183-189.
16. **Marczuk A., Turski A. 2009.** Wpływ warunków gospodarstwa na dobór maszyn rolniczych do produkcji bydła. Inżynieria Rolnicza. Nr 6 (115). 191-197.
17. **Siarkowski Z., Marczuk A. 2006.** Komputerowe projektowanie wyposażenia technicznego w budynkach dla bydła. Inżynieria Rolnicza. Nr 6 (81).
18. **Wrotkowski K. 1999.** Problemy określania oporów przepływu powietrza I wymiarowania wentylacji w chlewniach. Inżynieria Rolnicza. Nr 4.(10). 257-263.
19. **Pedersen S. 1996.** Dirnural variations in animal activity in buildings for cattle, pigs and poultry. Subresults from EU-project PL 900703. National Institute of Animal Science, Internal report No. 66. Denmark.
20. **Pedersen S., Sällvik K. 2002.** Heat and moisture production at animal and house levels. 4^{th} Report of Working Group on Climatization of Animal Houses. CIGR. Horsens.
21. **Pedersen S., Morsing S., Strom J. 2005.** Simulation of Heat Requirement and Air Quality in Weaner Houses for Three Climate Regions Using CIGR 2002 Heat Production Equations. Agricultural Engineering International: the CIGR Ejournal. Vol. VII. Manuscript BC 05 001.
22. PN-EN ISO 12569 2004. Izolacja cieplna w budynkach. Metoda gazu znacznikowego.

METODA OKREŚLANIA ILOŚCI POWIETRZA WENTYLACYJNEGO W BUDYNKACH DLA BYDŁA NA PODSTAWIE STĘŻENIA CO2

S t r e s z c z e n i e . Wielkość strumienia powietrza wentylacyjnego w budynkach dla bydła może być określana za pomocą stałej koncentracji gazu - wskaźnika, co wymaga skomplikowanych urządzeń do pobierania danych. Dwutlenek węgla emitowany przez zwierzęta może odgrywać funkcję gazu wskaźnika. W pracy przedstawiono metodę obliczania wielkości strumienia powietrza wentylacyjnego w budynkach inwentarskich wyposażonych w system wentylacji naturalnej. Wielkość strumienia może być określona na podstawie zmierzonego stężenia dwutlenku węgla i temperatury powietrza w pomieszczeniu dla zwierząt, przy zastosowaniu opracowanych równań. Obliczenia uwzględniają gęstość obsady i dzienną wydajność mleczną krów.

S ł o w a k l u c z o w e : budynek inwentarski, naturalna wentylacja, strumień powietrza, sposób obliczania.