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ANALYSIS OF THE VENTILATION AIR STREAM SIZE IN CATTLE BUILDINGS[1]

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ABSTRACT

The analysis concerns the size of the ventilation air stream, which is variable in time, in a cowshed with natural ventilation. The research was carried out in two buildings designed for dairy cattle, one has ventilation ducts, the other an air vent. The research covered measurement of internal and external air temperature, which is variable in time, air flow temperatures and velocity in air vents and the wind velocity. Temperature and velocity of air flow in particular ducts differed between each other. In the winter season, average air temperature in ducts was lower than the air temperature in the zone where animals stayed. The ventilation air stream size resulting from the measured flow velocities in ventilation ducts was compared to the theoretical size.

Introduction

Microclimate in the animal hall, and in particular, temperature, moisture and the air movement velocity are main factors, which influence the animal welfare and in consequence the milking capacity of cows (Daniel, 2008). One of the elements of the welfare is meeting the requirements concerning living in good environmental conditions. Such conditions are ensured by a well designed and constructed building and efficient ventilation system.

The ventilation air stream size is calculated based on the amount of carbon dioxide, water vapour or total heat produced by animals (Gaziński, 2012). The stream size, determined for the accepted conditions, is the basis for designing elements of natural ventilation. In the presently applied designing practice, dimensioning of elements of the natural ventilation system is based on the temperatures assumed for calculations:

– calculation temperature of external air, which depends on the climatic zone, where the designed building is located (PN-82/B-02403) or the designed external air temperature (PN-EN ISO 12831:2006),

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– calculation internal air temperature which depends on the animal species and the growth group (Journal of Laws, No 167, Item 1629).

Thermal dimensioning of inventory buildings is carried out based on the balance of profits and losses of sensible heat and total heat, formulated in the classic method of thermal dimensioning, in which heat losses for ventilation are calculated according to the water vapour or carbon dioxide criterion. Heat balance is also the basis for the simplified thermal conductivity coefficient method developed by Wolski and the method of thermal shaping of inventory buildings (Wolski, 2001). In these methods, established conditions are assumed, namely, only one calculation internal air temperature, which depends on the animal type and one external air temperature, which is related to the climatic zone. In real conditions, the inventory building is located in the constantly variable conditions of the surrounding. Temperatures and relative humidity of internal and external air are subject to dynamic changes and the heat exchange by transfer through partitions takes place according to the undetermined conditions (Głuski, 2013). The ventilation air stream is also variable in time because its size depends on the temperature difference between internal and external air and the wind speed.

Elements of the natural ventilation system influencing the air stream size may be divided into three groups:

– permanent elements, which do not change during the ventilation process; difference in the height between the roof ridge gap or the outlet of the ventilation duct and air vents,
– elements which can be regulated; width of the roof ridge gap, cross sectional area of ventilation ducts or air vents,
– factors variable in time depending on the weather; temperature and humidity of external air and the wind speed and direction.

Assessment of the real size of the ventilation air stream is very difficult to carry out on account of complexity of this process and great number of factors, which are variable in time, which influence it. There are several methods which enable determination of the ventilation air stream size:

1. Gas leaks detection method (PN-EN ISO 12569:2013). There are three methods of investigating the size of air stream exchanged in the building as a result of ventilation and infiltration which use tracer gas:
   – tracer gas failure method,
   – permanent injection method,
   – permanent concentration method.
2. Method of air flow velocity measurement in ventilation ducts.
3. A method which uses carbon dioxide concentration measurement in the animal hall and inventory of a herd (Głuski, 2011).
4. A method which uses equation of air movement in natural ventilation.

Kiwan et al. (2012) carried out research on the ventilation air stream size, using the tracer gas method with the use of radioisotope Krypton-85, measurement of the air flow velocity in air vents and the method which uses equations of air movement in the natural ventilation. Research was carried out in two various cowsheds and two weather periods. The determined values of air stream with those three methods resulted in the Pearson coefficient of correlation 0.59-0.86.

The objective and the scope of the study

The objective of the study is to carry out analysis of the dynamic ventilation air stream and variables in the daily cycle of factors, which influence it. The basis of analysis consisted in measurements carried out in two buildings for the dairy cattle equipped with various systems of gravity ventilation.

Methodology of research

Research was carried out in two buildings for dairy cattle on the territory of Lubelskie Voivodeship. The building was located in Glinnik locality (measurement carried out on 26th January 2013); the building has a utility attic. The animal hall consists of two rows with a central feeding passage. It includes a barn rearing system, stands for cows – individual and tied, single coops and group coops. The building has four vent ducts with a round cross-section *Φ* 57 cm and is 630 cm high.

The second building is located in Przegaliny locality (measurement carried out on 14th January 2014); it is a hall type building without a utility attic, ground-floor with a non-symmetric flat roof, in which a transparent hinged roof ridge gap is located, which serves as lighting and ventilation of the building. Cows are maintained in a free-stall system and they are fed from the feeding passage. On both sides of the ridge there is a roof ridge gap, which is 25 cm wide and 49.4 m long. Air vents, which are 25 cm wide, are located in the side walls of the building under the eaves. Difference in height between the air vent and the roof ridge gap is 3.50 m. In the described buildings, research included measurements of temperature and humidity of internal and external air as well as temperature and air flow velocity at the inlet to the ventilation ducts or in the ventilation gap. Measurements of temperature and air flow velocity in trunks were carried out with thermoanemometers AVM-07 (the scope of operation 0.0-45.0 $m \cdot s^{-1}$, accuracy 3%), whereas measurements of air temperature in the animal hall and outside with COMARK sensors (the scope of operation from -40.0 to +70.0ºC, accuracy 0.1ºC). Sensors and recorders of temperature and air flow velocity were programmed to carry out the readout and the record of measurement results in 300 second intervals. One day was assumed as a basic period of time, when analyses were carried out.

A formula, which describes the air velocity in ventilation ducts provided by Hellickson and Walker (1983) was accepted for calculation of the theoretical size of the ventilation air stream:

$$V_d = \Theta\sqrt{\frac{2gH(T_i - T_o)}{T_i}} \quad (m \cdot s^{-1}) \tag{1}$$

where:

- V_d – air flow velocity in the dunct, ($m \cdot s^{-1}$),
- Θ – coefficient, which includes frictional resistance of air on the internal surface of the duct,
- g – gravitational acceleration, ($m^2 \cdot s^{-1}$),
- H – difference between the inlet and outlet of the duct, (m),
- T_i – internal air temperature, (K),
- T_o – external air temperature, (K).

The following values of the coefficient Θ are accepted for calculations:

- ventilation with a roof ridge gap 0.80(0.86)
- single ventilation trunks 0.73(0.79)
- composite well 0.68(0.74)

The brackets include the values of the coefficient Θ V for air vents without a cover.

The ventilation air stream depends on the cross sectional area of the ventilation duct or a ventilation gap and the air flow velocity.

$$L = \sum_{i=1}^{n} A_i \cdot V_i \tag{2}$$

where:

L – ventilation air stream variable in time, ($m^3 \cdot s^{-1}$)
A_i – cross-sectional area of i-duckt, (m^2)
V_i – the air flow velocity variable in time in i-trunk, ($m \cdot s^{-1}$)
n – number of trunks

Results

Each ventilation trunk (Glinnik) is made of 7 identical metal elements which results in their identical dimensions and air frictional resistance. Despite this, differences in the air flow velocity in particular trunks occurred. The measurement results were presented in figure 1 (trunks no 1 and 3) and figure 2 (trunks 2 and 4).

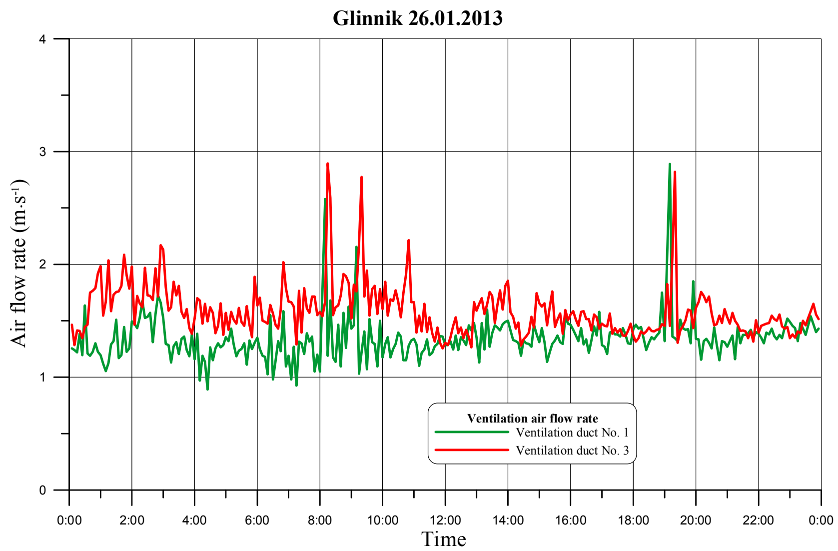

Figure 1. Air flow velocity in ventilation ducts no 1 and 3

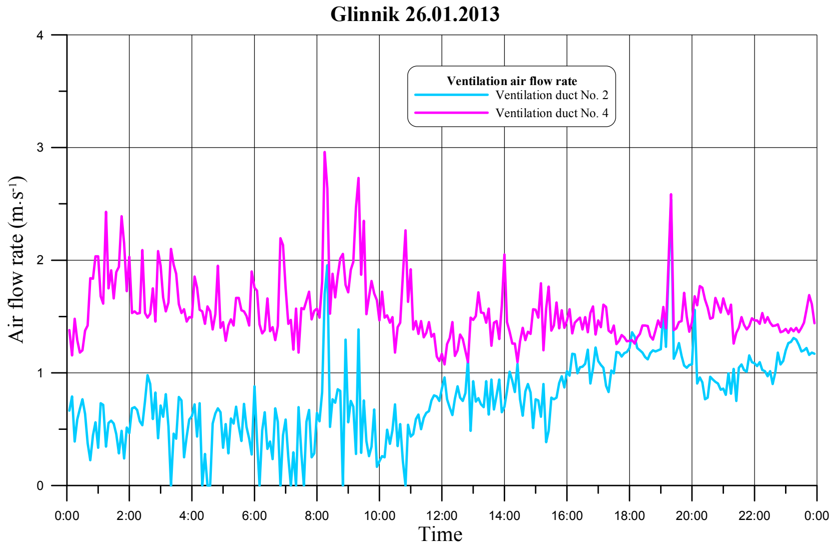

Figure 2. Air flow velocity in ventilation trunks no 2 and 4

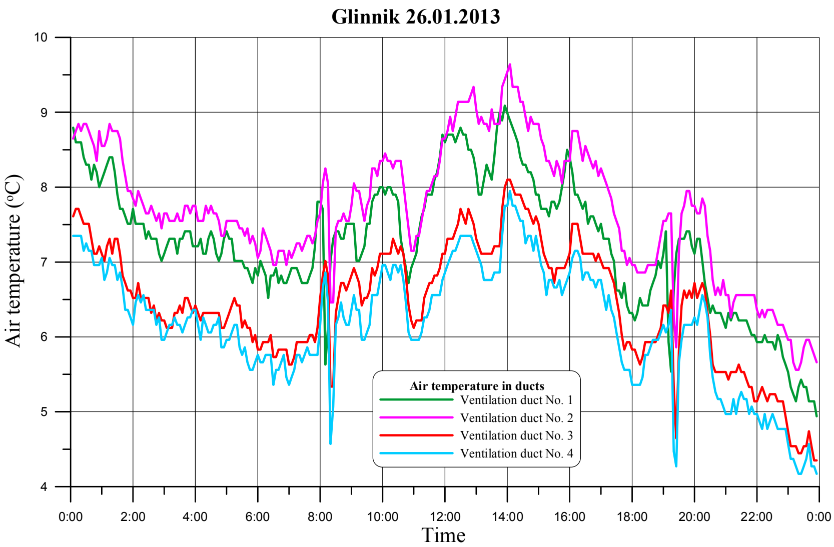

Figure 3. Air temperature at the inlet to particular trunks

Differences in the air flow velocity in ventilation trunks result from air temperature distribution in the animal hall. Daily changes of air temperature in ducts are presented in figure 3. Despite the fact, the inlets to ventilation trunks are at the height of the ceiling over the animal hall, the average air temperature in all trunks was lower than the average air temperature in the animal hall (fig. 4).

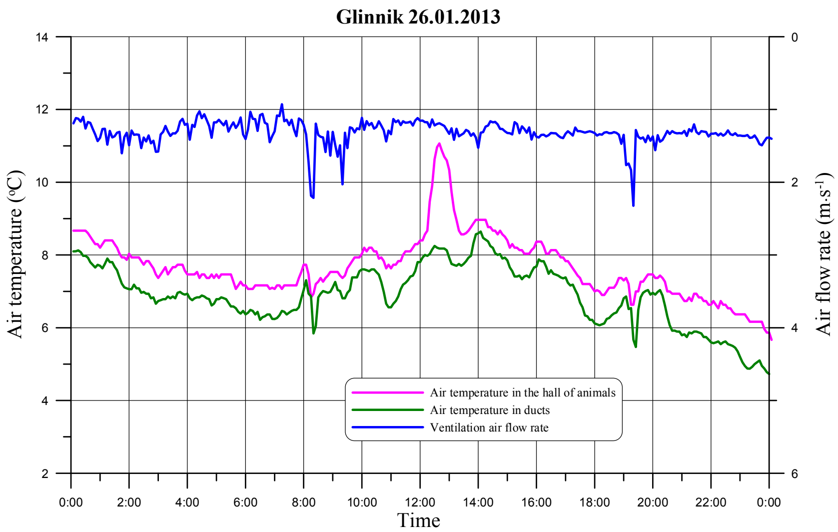

Figure 4. Average temperature in ventilation ducts, in the animal hall and the average air flow velocity in four ducts

Figure 5 presents results of measurements and calculations of the ventilation air stream size and the difference of the internal and external air temperatures.

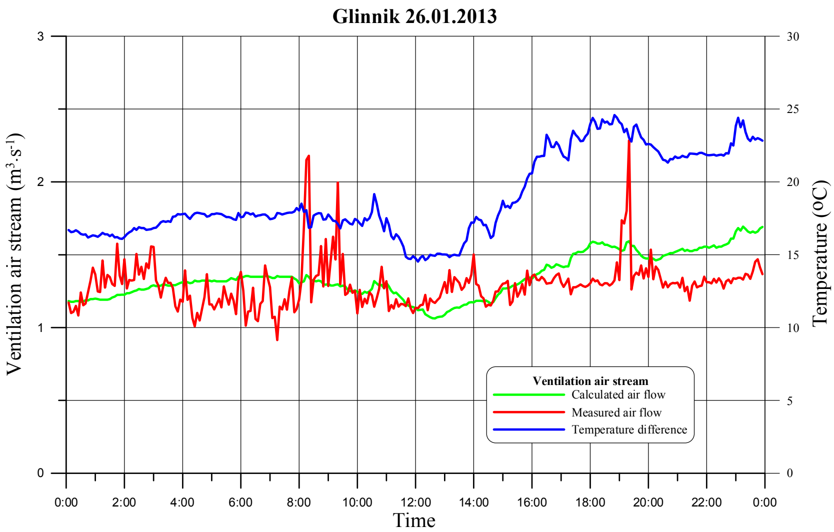

Figure 5. Ventilation air stream measured and calculated and the difference between internal and external air temperature

The building for the dairy cattle located in Przegaliny locality has a natural ventilation system with a roof ridge gap, which is 25 cm wide on both sides of a ridge. Anemometers for measurement of the ventilation air flow velocity were placed in the air vent.

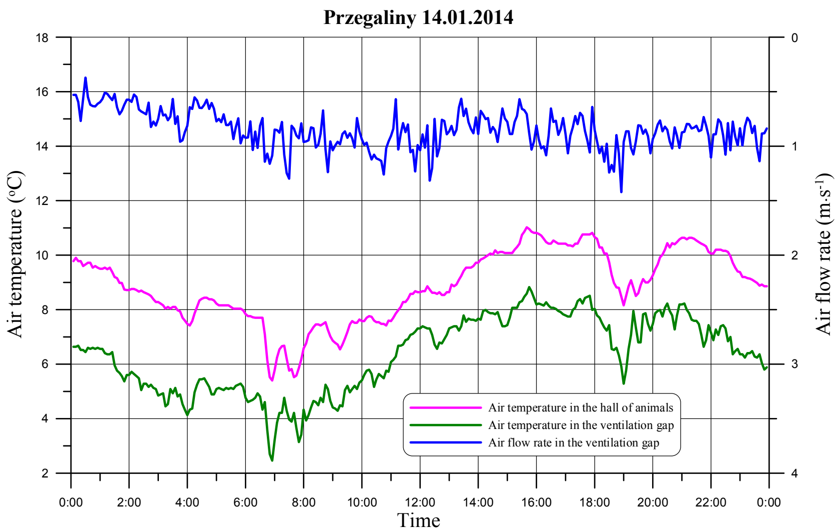

Figure 6. Air temperature in the ventilation gap, ventilation ducts and the average air flow velocity in the air vent

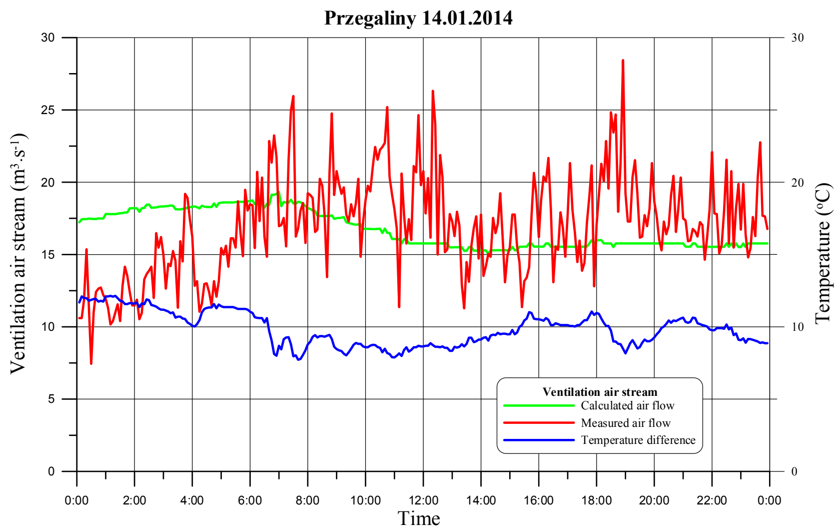

Figure 7. Measured and calculated ventilation air stream and the difference between internal and external air temperature

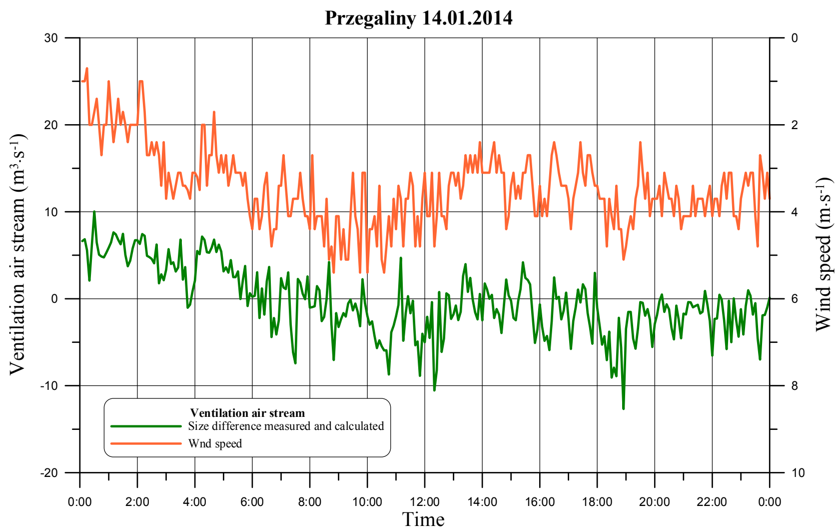

Figure 8. Size difference measured and calculated of the ventilation air stream and the wind speed

Figure 7 presents measured and calculated values of ventilation air stream, which are variable in time and the difference between internal and external air temperature. Difference in the measured and calculated size of the ventilation air stream results from the wind impact on the efficiency of the ventilation system but the relation is inversely proportional (fig. 8).

Conclusion

Real values of the ventilation air stream, which is variable in time, in the inventory building are subject to frequent fluctuations and differ from the calculation values. It follows from the great number of difficult to predict and describe factors which influence the size of this stream. For example the wind impact or opening the door and gates related to the performed technological processes. Based on the research and analyses one may make the following conclusions:

1. The size of the ventilation air stream, variable in time, depends on the variable internal and external air temperatures and the temperature distribution in the animal hall.
2. In the building with chimney ventilation, although all ventilation ducts have the same cross sectional area and the same height, the air flow velocity was varied. These differences result from various air temperatures at the inlet to the duct, but high temperature corresponds to lower air flow velocity.
3. In the investigated winter season, average air temperature in ducts was lower than the temperature in the zone where animals stayed.

4. Difference in the measured and calculated size of the ventilation air stream results from the wind impact on the efficiency of the ventilation system but the relation is inversely proportional.
5. The ventilation air stream is dynamic in nature. Therefore, designing the natural ventilation system should use the simulation of the system operation based on the surrounding conditions, which are variable in time.

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ANALIZA WIELKOŚCI STRUMIENIA POWIETRZA WENTYLACYJNEGO W BUDYNKACH DLA BYDŁA

Streszczenie. Analiza dotyczy wielkości zmiennego w czasie strumienia powietrza wentylacyjnego w oborach z wentylacją naturalną. Badania przeprowadzono w dwóch budynkach dla bydła mlecznego, jeden posiada kominowe kanały wywiewne drugi kalenicową szczelinę wentylacyjną. Badania obejmowały pomiary zmiennych w czasie temperatur powietrza wewnętrznego i zewnętrznego, temperatur i prędkości przepływu powietrza w wywiewnych otworach wentylacyjnych oraz prędkość wiatru. Temperatura oraz prędkość przepływu powietrza w poszczególnych kanałach różniły się między sobą. W okresie zimowym średnia temperatura powietrza w kanałach była niższa niż temperatura powietrza w strefie przebywania zwierząt. Wielkość strumienia powietrza wentylacyjnego wynikająca z pomierzonych prędkości przepływu w kanałach wentylacyjnych porównano z wielkością teoretyczną.

Słowa kluczowe: obora, wentylacja naturalna, strumień powietrza wentylacyjnego, mikroklimat