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24-HOUR MICROCLIMATE CONDITIONS IN LIVESTOCK BUILDING

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ABSTRACT

The size of all sensible heat balance components in livestock building varies in time, because it depends on time-varying weather factors. On the example of two buildings, sensible heat balance was shown on a daily basis. Measurements carried out in winter and spring in two livestock buildings with usable attics included measurements of air temperature and humidity inside and outside, air velocity in ventilation channels, and wind speed. Measuring devices were designed to record the results of measurements at intervals of 300s. During each such time interval, sensible heat losses by ventilation, heat losses by permeation through the barrier construction, and the amount of sensible heat produced by the animals were calculated. The results of measurements were shown in graphs. The study is important for the development of animal livestock building.

Introduction

A livestock building is a complex thermodynamic system in which complex and time-varying thermal processes take place. Functional layout of the building can be a single animal production hall or can be composed of several different rooms such as a livestock hall, feed room, milk storage room, milking parlor or usable attic. Each of these rooms is a system separated by building partitions into which thermal energy is transferred or discharged, depending on environmental conditions. The animal hall is of a special nature because it has a heating source, which is the living livestock (Głuski, 2008).

The microclimate in the production hall of the livestock building is the result of complex processes that occur in the livestock building (Głuski, 2007) and environmental impacts, the most important feature of which is the outdoor climate. Internal processes are heat and steam being emitted by animals, heat transfer through the building partitions, and the exchange of air during ventilation. The most important external factors are air temperature and humidity, however, the strength and direction of the wind and sunlight are of great importance, as well. All these factors are variable in time, interrelated and most of them interact with each other.

The complexity of the entire problem is that the heat balance calculation methods assume the heat transfer for the conditions being set under the assumption for a single outdoor temperature calculation value (determined for climatic zone, in which the building is placed), and for a single internal air temperature design value which varies according to the type of animal being kept there (Siarkowski and Głuski 2000, 2004). According to the climatic zone, there are also accepted calculation temperatures in the usable attic and in rooms adjacent to the livestock hall. In Poland, the thermal dimensioning of livestock buildings is made based on the simplified TPI method (Thermal Properties Index) (Wolski, 2001) and the Polish Standard PN-82/ B-02402 and PN-EN ISO 12831:2006. Striving to provide proper microclimate conditions for animals raises the need for simulation studies on thermal phenomena and processes in livestock building (Pedersen et al., 2005). The microclimate of the room will affect the qualitative state of litter and animal nutrition. Maintenance of livestock facilities at a suitable temperature and humidity affects the maintenance of bacteriological purity of the room. These aspects have an influence on the quality and quantity of milk produced by dairy cows (Dolezal et al., 2011).

Materials and Methods

Thermal design methods for livestock buildings that are being used in the design practice are based on the classical method and they assume constant computational temperatures and heat exchange, according to the conditions being set. Such an assumption causes that conditions used in calculations may occur very rarely and never occur during the exploitation life of the building. The aim of the study is the analysis of time-varying elements of the sensible heat balance, calculated based on the variables calculated under the actual environmental conditions. The analysis was based on measurements derived from two livestock buildings, conducted in winter and spring seasons.

The research studies were conducted during winter and spring seasons in two livestock buildings in Lubelskie Voivodeship in locations of Glinnik and Komarów. The buildings have a usable attic, double-breasted milk cattle hall with a central corridor for feeding animals, separate closed stands for cows, individual and group coops for calves. Both cowsheds are equipped with a system of natural ventilation:

- the building in the town of Glinnik (measurement tests on 26.01.2013) has four exhaust channels with round cross section ϕ57 cm and the height of 630 cm,
- the building in the town of Komarów (measurements on 27.04.2013) has four exhaust channels with a cross section of 70x70 cm and the height of 570 cm.

In the described buildings, the research study was focused on temperature and humidity measurements of indoor and outdoor air, the speed of air stream in ventilation ducts and the air pressure and wind speed. Measurements of air velocity in ventilation systems were performed by using the AVM-07-type anemometers (operating range of 0.0÷45.0 $m \cdot s^{-1}$, accuracy 3%), the temperature and relative humidity by COMARK sensors (the operating range from -40.0 to + 70,0ºC, the accuracy of 0.1ºC), while the pressure measurements of wind speed by using the Viking AB 02049 weather station (the range of atmospheric pressure was 300÷1100 hPa).

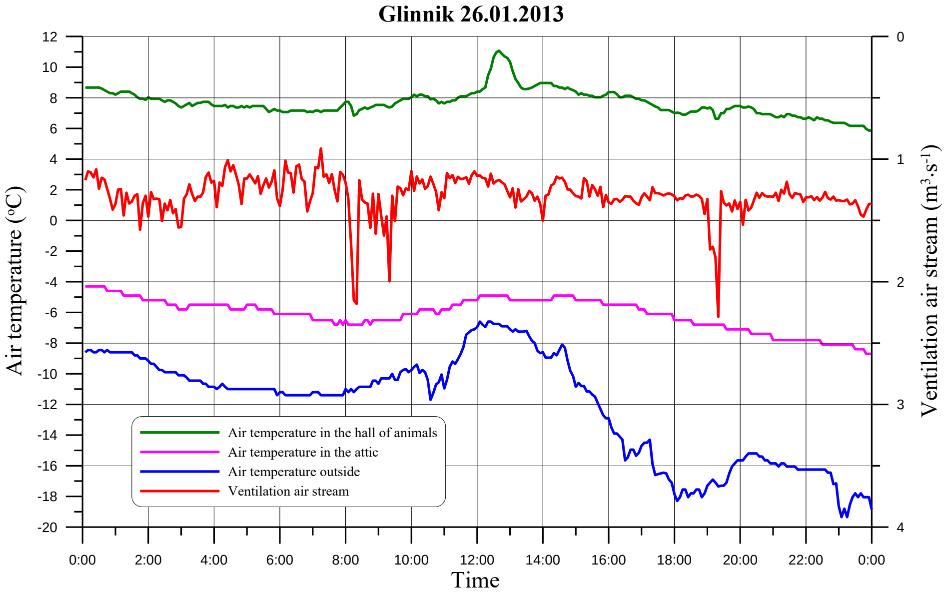

Figure1. Air temperature in livestock hall, in the attic, and outside, as well as the ventilation air stream. Glinnik- 26.01.2013

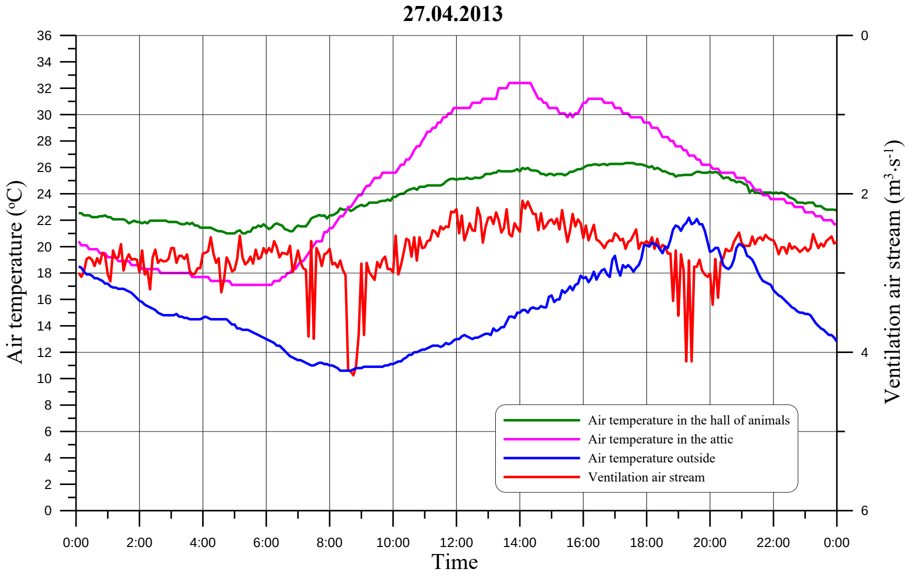

Figure 2. Air temperature in the hall of animals, in the attic and outside, as well as the ventilation air stream. Komarów – 27.04.2013

Temperature and air velocity sensors and recorders have been programmed for reading and recording measurement results at intervals of 300 seconds. The basic time period being adopted for the analyzes, in which they were carried out, was one day. The measurement results of temperatures in the building in the town of Glinnik (26.01.2013) is shown in Fig. 1, while in the town of Komarów (27.04.2013) in Fig. 2.

Heat balance type-varying components

The analyzed period of one day is divided into 288 intervals equal to 300 seconds. For each time interval the sensible heat balance components were computed for the parameters at this time parameters of indoor and outdoor air. The time-varying ventilation air stream rate depends on the sectional area of the ventilation channel and the air stream velocity.

$$L(k) = \sum_{i=1}^{n} A_i \cdot V_i(k) \quad (\mathrm{m^3 \cdot s^{-1}}) \tag{1}$$

where:

L(k) – the size of the ventilation air stream in the k-th time interval, ($\mathrm{m^3 \cdot s^{-1}}$)
Ai – the sectional area of the i-th channel, ($\mathrm{m^2}$)
Vi(k) – the air stream velocity in the i-th channel, and in the k-th time interval, ($\mathrm{m \cdot s^{-1}}$)
n – the number of channels

Sensible heat losses due to ventilation depend upon the ventilation air volume and the temperature difference between the air inside and outside:

$$\Phi_{wj}(k) = L(k) \cdot c_{po}(k) \cdot [t_i(k) - t_e(k)] \quad (\mathrm{W}) \tag{2}$$

where:

Φwj(k) – the sensible heat loss due to ventilation in the k-th time interval
cpo(k) – the air heat capacity volume in the k-th time interval, ($\mathrm{J \cdot m^{-3} \cdot K^{-1}}$)
ti(k) – the interior air temperature in the k-th time period, (°C)
te(k) – the ambient air temperature in the k-th time interval, (°C)

The Boyle's Law and Charles' Law to the following dependence (Jones, 2001):

$$p \cdot V = m \cdot R \cdot T \tag{3}$$

where:

p – the absolute gas pressure, (Pa)
V – the volume of the gas, ($\mathrm{m^3}$)
m – the mass of the gas, (kg)
R – the individual gas constant for dry air R= 287 $\mathrm{J \cdot kg^{-1} \cdot K^{-1}}$
T – the absolute temperature of the gas, (K)

Gas density ρ is the ratio of weight to volume basis and taking into account depending 3:

$$\rho = \frac{m}{V} = \frac{p}{RT} \ (\mathrm{kg \cdot m^{-3}}) \tag{4}$$

The air density at the ti(k)-th temperature in the k-th time interval i`s equal to:

$$\rho(k) = \frac{p(k)}{R \cdot T(k)} = \frac{p(k)}{287 \cdot (273 + t_i(k))} \ (\mathrm{kg \cdot m^{-3}}) \tag{5}$$

The volume air heat capacity in the k-th time interval is equal to:

$$c_{po}(k) = c_p \cdot \rho(k) \ (\mathrm{J \cdot m^{-3} \cdot K^{-1}}) \tag{6}$$

where:
Cp – specific heat of the air equals to 1005 $\mathrm{J \cdot kg^{-1} \cdot K^{-1}}$.

Heat losses due to permeation through building partitions depend on the average Ua heat transfer coefficient and the temperature difference between the air inside and outside:

$$\Phi_b(k) = A_b \cdot U_a \cdot [t_i(k) - t_e(k)] \ (\mathrm{W}) \tag{7}$$

where:
Φb(k) – heat losses due to building partitions in the k-th time interval
Ab – area of building partitions, ($\mathrm{m^2}$)
Ua – the average heat transfer coefficient due to partitions, ($\mathrm{W \cdot m^{-2} \cdot K^{-1}}$)

Heat losses due to permeation through the roof of the livestock hall depend on the heat transfer coefficient for the roof and the temperature difference between the air temperature in the animals' hall and the ambient temperature in the attic:

$$\Phi_s(k) = A_s \cdot U_s \cdot \left[t_i(k) - t_p(k)\right] (\mathrm{W}) \tag{8}$$

where:
Φs(k) – heat losses due to the roof in the k-th time interval, (W)
As – surface area of the ceiling above the animals hall, ($\mathrm{m^2}$)
Us – heat transfer coefficient for the roof, ($\mathrm{W \cdot m^{-2} \cdot K^{-1}}$)
tp(k) – the air temperature in the attic in the k-th interval, (°C)

The total amount of heat being produced by dairy cows (Pedersen, 2002):

$$\Phi_{zc}(k) = 5.6m^{0.75} + 22Y_1 + 1.6 \cdot 10^{-5} p^3, (\mathrm{W}) \tag{9}$$

where:
Φzc(k) – the total heat emitted by animals in the k-th time interval, (W)
m – cow's weight, (kg)
Y1 – daily milk production, (kg)
P – duration of pregnancy, (days)

Taking into account the ambient temperature with respect to the HPU unit:

$$\Phi_{zc}(k) = 1000 + 4 \cdot [20 - t_i(k)] \text{ (W)} \tag{10}$$

The amount of sensible heat being produced:

$$\Phi_{zj}(k) = 0.71 \cdot \Phi_{zc}(k) - 0.408 \cdot t_i^2(k) \text{ (W)} \tag{11}$$

where:

Φzj(k) – the sensible heat being emitted by animals in the k-th interval, (W)
HPU – heat production unit equals 1000W of total heat at the temperature of 20 (°C)

Elements of heat balance calculated for individual intervals in the studied buildings for dairy cattle, Fig. 3 and 4.

In this calculation the total loss of sensible heat model in the respective time intervals changes to a larger extent in a day than the amount of sensible heat flux emitted by the animals, which also depends on the temperature in the animal hall but is more stable over time. In Table 1 compares the average-daily temperatures and the heat fluxes.

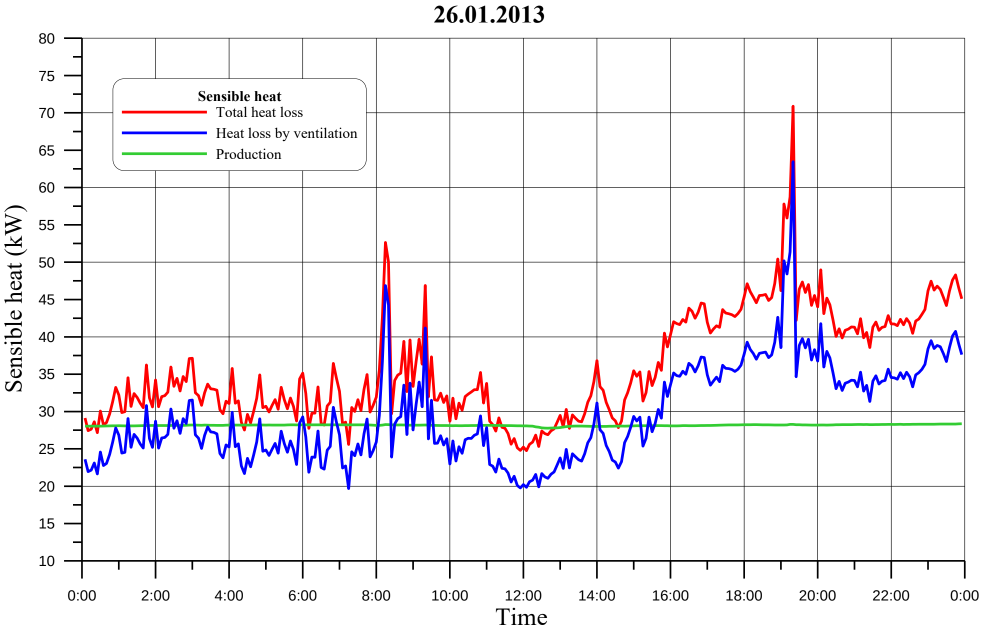

Figure 3. Total heat losses, sensible heat losses due to ventilation, and sensible heat production due to animals. Glinnik – 26.01.2013

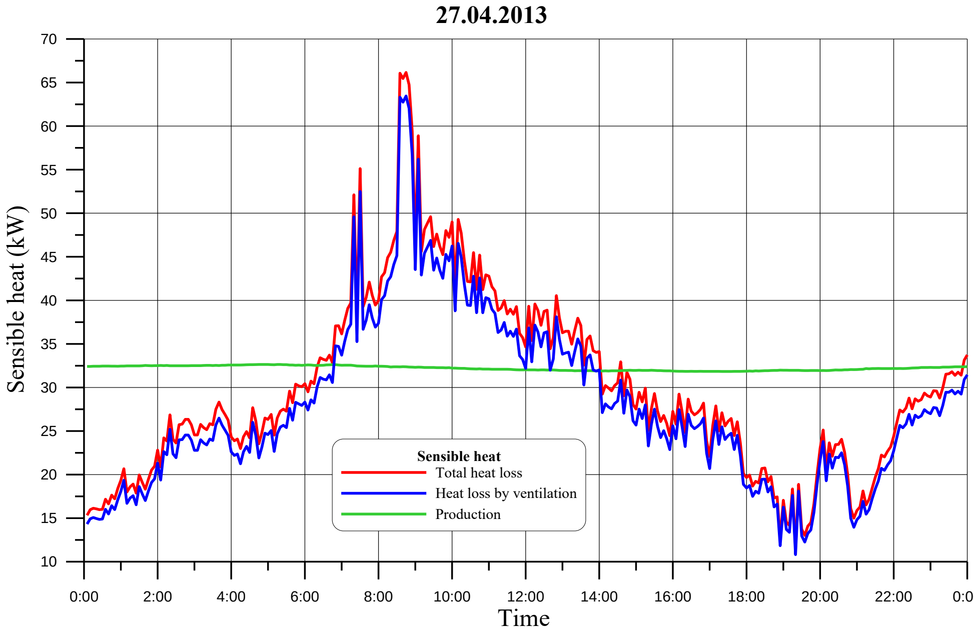

Figure 4. Total loss of heat, sensible heat loss by ventilation and sensible heat production by animals. Komarów – 27.03.2013

Table 1.
Average-24h temperatures and heat fluxes

Location Date	Average air temperature			Average heat fluxes			
	in the animal hall (ºC)	outdoor (ºC)	variation (ºC)	Sensible heat losses			Emission (kW)
				due to ventilation (kW)	due to penetration (kW)	total (kW)	
Glinnik 26.01.13	7.70	-12.11	19.81	29.81 (82.6 %)	6.28 (17.4 %)	36.09 (100 %)	28.54
Komarów 27.04.13	23.88	15.31	8.57	28.07 (93.7%)	1.90 (6.3%)	29.97 (100%)	35.11

Conclusions and Results

The total loss of sensible heat in the livestock building consists of heat loss due to ventilation and heat losses due to penetration through building partitions. They constitute time-varying heat stream, the size and the variation of which depends during a day on the outside climate variable factors, and mainly on the deference between the inside and outside air temperatures. Heat losses by permeation depend on thermal insulation quality of the entire building, they are much lower than the heat losses due to ventilation, and are less than 20 % of the total heat loss − 17.4 % over the winter period (Glinnik 26.01.2013) and 6.3% over the spring (Komarów 27.04.2012). The size of the average heat losses by ventilation is comparable (29.81 and 28.07 kW), despite the fact that there is a different temperature variation (19.81 and 8.57°C). This results from the increased ventilation air stream in spring period (2.74 $m^3 \cdot s^{-1}$) than in the winter months (1.30 $m^3 \cdot s^{-1}$), Figures 3 and 4 and Table 1.

Sensible heat fluxes emitted by animals are more stable over time than the heat loss, and their average-24-hour values (28.54 and 35.11 kW) differ significantly from the average values of the total heat loss (36.09 and 29.97 kW), Table 1. This results from the adopted computational model, which does not take into account the heat being stored by the building components and devices of the livestock hall. The heat is received or given away by these elements, depending on the temperature distribution, and it affects the thermal stability of the hall for animals. The microclimate of the livestock buildings is also very important for the quality and quantity of milk being produced by dairy cows.

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MIKROKLIMAT BUDYNKU DLA BYDŁA W UJĘCIU DOBOWYM

Streszczenie. Wielkość wszystkich składników bilansu ciepła jawnego w budynku inwentarskim jest zmienna w czasie po-nieważ zależy od zmiennych w czasie czynników pogodowych. Na przykładzie dwóch budynków przed-stawiono bilans ciepła jawnego w ujęciu dobowym. Pomiary przeprowadzone w zimie i na wiosnę w dwóch budynkach dla bydła z poddaszem użytkowym obejmowały pomiary temperatury i wilgotności powietrza wewnętrznego i zewnętrznego, prędkości przepływu powietrza w kanałach wentylacyjnych oraz ciśnienia at-mosferycznego i prędkości wiatru. Urządzenia pomiarowe zostały zaprojektowane na rejestrację wyników pomiarów w odstępach co 300s. W każdym z takim przedziale czasowym obliczone zostały straty ciepła jawnego drogą wentylacji, straty ciepła drogą przenikania przez przegrody budowlane oraz ilości ciepła jawnego produkowanego przez zwierzęta. Wyniki pomiarów i obliczeń przedstawiono na wykresach.

Słowa kluczowe: mikroklimat, budynek inwentarski, bilans ciepła jawnego