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Effect of construction shape and materials on indoor microclimatic conditions inside the cowsheds in dairy farms

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Abstract. The aim of this paper is to present the results of microclimatic research focused on the indoor conditions in cowsheds and milking parlours in two dairy farms. The attention is paid mainly to the construction and materials used for buildings, which can influence together with technological equipment and system of ventilation the microclimatic conditions inside the cowsheds. In the frame of this research main parameters of internal and external properties of climate (air temperature, humidity, globe temperature, THI, BGHI and concentration of CO_2) during the hot summer were measured and evaluated. Results of long time and short time measurements show very important role of used materials and shape of buildings. The research results show that the use of principles of passive air conditioning can contribute significantly to the improvement of internal microclimate. Reduced amplitude of temperature oscillation was 42.4% of amplitude of outside air temperature in cowshed with massive construction and 91.7% in modern light building. The average phase shift of temperature oscillations, expressed as a time delay of internal temperature rise behind the external temperature rise was about 2.8 hours and time delay of drop of internal temperature behind external temperatures drop was 3.3 hours in massive cowshed. The same parameters in modern light cowshed were only 1.1 hours and 0.5 hours.

Key words: air temperature, massive construction, solar radiation, temperature oscillations.

INTRODUCTION

Problems of thermal comfort environment of cattle are receiving considerable attention in recent decades, especially in terms of thermoregulatory abilities of cattle. Modern dairy cows are producing very high milk yield; therefore they are under metabolic stress. To enable the milk production to their potential, the housing conditions should reduce any additional stress by microclimate inside the cowsheds.

Thermal state of the indoor environment is characterized by thermal and humidity variables which affect the resulting mental and physical state of an animal in agricultural buildings. As a consequence of the analysis of thermal environment is a formation of optimal conditions for animal organism. There are small differences between recommendations in published articles and books about optimal parameters of indoor environment mainly air temperature and humidity; nevertheless it can be concluded that the required optimal temperatures for cowshed are 10–20 °C (minimum 2 °C, maximum 25 °C). In milking parlour during a winter period is optimum 14–16 °C (minimum

10 °C), in summer period is required optimal temperature in the range of 14–22 °C (maximum 26 °C). These recommended values of temperature are usually completed by recommendation of suitable ventilation systems (Chiumenti, 2004; Choupek & Suchy, 2008; Koznarova & Klabzuba, 2008; Zejdova et al., 2014; Papez & Kic, 2015; Rajaniemi et al., 2015).

Thermal state of the indoor environment is also influenced by relative humidity. High water vapour content in the air reduces the possibility of cooling the body by evaporation. It can cause heat stress already at a relatively low temperature of indoor environment. Relative humidity should by ideally in the range of 40–80%. The maximum allowable value of relative humidity according to Czech standard CSN 73 0543–2 is 85%. Long–term exposure of relative humidity above 85% adversely affects the organism and apparatus and could damage wooden elements of buildings. (Kic & Broz, 1995; Kunc et al., 2007; Pavelek & Stetina, 2007; Papez & Kic, 2013; Zejdova et al., 2014; Papez & Kic, 2015).

Effect of combinations of temperature and humidity is included in the temperature–humidity index (THI). This index is widely used to describe the heat stress. THI value below 70 is considered as comfort for cattle. THI in the range of 70–78 is considered as stressful and values higher than 78 cause extreme suffering (the organism is enable to maintain the thermoregulatory mechanisms or normal body temperature). (Armstrong, 1994; Zejdova et al., 2014). Black globe humidity index (BGHI) is also a good indicator of heat stress. It is based on similar measurement method, associating the use of black globe temperature instead of dry bulb temperature for adding the solar radiation effect to the principal of THI. This method is used in different research works of summer heat stress (Zewdie & Kic, 2015; Dalcin et al., 2016; Zewdie & Kic, 2016).

In summary, cattle thanks to their thermoregulation ability can better adapt to the lower air temperature and harder tolerate high temperatures. Therefore, the aim of this paper is to show the measurement results of main microclimatic parameters in different types of buildings in dairy farms in hot summer period. Measurement results should verify the influence of construction shape and materials on indoor microclimatic conditions.

MATERIALS AND METHODS

This research work and measurements were carried out in two dairy farms situated in the same central part of Czech Republic. Summer season with maximum daily temperatures in the Czech Republic are usually months July and August. The year 2015 was very hot in the Czech Republic and therefore it was very suitable for carrying out the experiments and measurements of microclimate. There are usually 46 summer days (mean temperature over 25 °C) in the Czech Republic, but in 2015 it was 60 days, the number of tropical days (temperature over 30 °C and at night does not drops below 20 °C) is usually 9, but in 2015 it was 35 days. The warmest day of the year was August 8th 2015 (meteoforum.e-pocasi.cz, 2017).

Buildings studied in the first dairy farm are: a modern cowshed CS1 for cows and milking parlour MP1. Buildings studied in the second dairy farm consist from old cowshed CS2 and milking parlour MP2.

The modern cowshed CS1 (Fig. 1) is used for housing of 100 cows in group pens with straw bedding. The non-insulated steel construction (length 40.5 m, width 12 m) with side feed table has a natural ventilation. The roof with central ridge slot (6 m height) is covered by plastic plates, partly completed by translucent fibreglass, gable walls are partly made from wood and partly from PVC mesh; side walls are made from PVC mesh which can be covered by the vertically movable PVC tarpaulin. It creates the protection against rain, snow, sunshine and wind. The herringbone milking parlour MP1 is a traditional brick construction, which is closed, insulated and ventilated by forces ventilation during the milking process.

The cowshed CS2 (Fig. 2) in second dairy farm is very old building, constructed from massive stone and brick walls with vaulted ceiling used for housing of 80 cows in individual cubicles with straw bedding. The herringbone milking parlour MP2 is situated in the same massive building as the cowshed CS2.

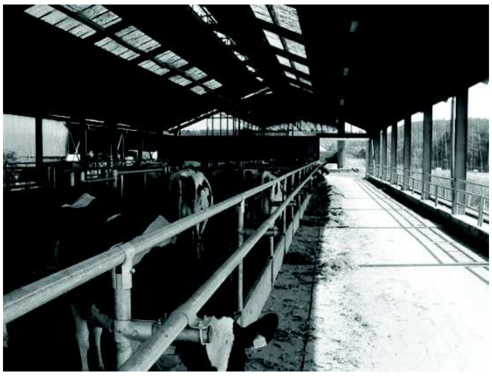

Figure 1. The modern cowshed CS1.

Figure 2. The old massive cowshed CS2.

Long-term measurements were carried out during the days of highest summer temperatures since 11th to 14th August 2015 and short-term measurements were carried out on August 11th, during the warmest hours of the day since 10 a.m. to 5 p.m.

Air temperatures and relative humidity were measured by data loggers ZTH65 outside and inside the buildings with registration at intervals of 15 minutes during four days (long-time measurement). Parameters of ZTH65 are: temperature operative range –30 to +70 °C with accuracy ± 0.4 °C and operative range of relative humidity 5–95% with accuracy ± 2.5%.

The thermal comfort in the space was continuously measured during the short-time experiments by globe temperature which includes the combined effect of radiation, air temperature and air velocity (measured by globe thermometer FPA 805 GTS with operative range from –50 to +200 °C with accuracy ± 0.1 °C and diameter of 0.15 m) together with temperature and humidity of surrounding air measured by sensor FHA 646–21 including temperature sensor NTC type N with operative range from –30 to +100 °C with accuracy ± 0.1 °C, and air humidity by capacitive sensor with operative range from 5 to 98% with accuracy ± 2%.

Furthermore the concentration of CO_2 was measured by the sensor FY A600 with operative range 0–0.5% and accuracy ± 0.01%. All these data were measured continuously in all described animal houses and stored at intervals of one minute to measuring instruments ALMEMO 2590–9, ALMEMO 2690–8 and ALMEMO 5990–2 during approximately one hour (time for stabilization of sensors).

Effect of combinations of temperature and relative humidity is included in the THI. According to (Zejdova et al., 2014) the THI is determined by the equation (1). Calculation of the BGHI is based on the results from short time measurements with the use of black globe temperature instead of dry bulb temperature, according to the Eq. (2).

$$THI = 0.8 \cdot t_i + \frac{(t_i - 14.4) \cdot RH_i}{100} + 46.4 \tag{1}$$

where: THI – temperature–humidity index, –; t_i – internal temperature of air, °C; RH_i – internal relative humidity of air, %.

$$BGHI = 0.8 \cdot t_g + \frac{(t_g - 14.4) \cdot RH_i}{100} + 46.4 \tag{2}$$

where: $BGHI$ – black globe–humidity index, –; t_g – globe temperature, °C.
For evaluation of THI are usually used the following limit values. If THI ≤ 65 it means comfort state; if THI is from 66 to 79 it means alert state, prolonged exposure occurs fatigue; and if THI ≥ 80 it means discomfort, if THI ≥ 84 it is dangerous, heat stress is highly probable if the activity continues.

RESULTS AND DISCUSSION

The main objective of this article is a presentation of results of measurement of main microclimatic research focused on the indoor conditions in several agricultural buildings used for housing of cattle in dairy farms, a comparison of obtained results with values recommended in relevant standards, and an analysis if the use of principles of passive air conditioning can contribute to the improvement of internal microclimate.

Problems of ventilation and suitable environment were studied (Naas et al., 1997) in cowsheds with loose housing in Brazil in order to evaluate and determine the influence of environmental and temperature on milk production. Heat stress of dairy cows was reflected in the decrease in milk yield. Reduction of heat stress for the best cow herds is very important. Problems of reduction of energy consumption for ventilation in cowsheds emphasize in their publication (Frorip et al., 2012).

Basic parameters of microclimate in unheated cowshed for cows during the summer period are presented in the publication (Sada et al., 2012). Average outdoor temperature, however, was relatively low (16.33 °C) and therefore the average internal temperature in cowshed was only17.12 °C.

Results of research on relation between the indoor and outdoor climate in uninsulated cowsheds are presented in publication (Reppo & Mikson, 2006). The average summer outside temperatures were from 14.54 to 17.26 °C. But there is not available publication focused on the influence of building mass on the temperature shift in time together with reduction of indoor temperatures in the cowsheds.

The results of long-time measurement of air temperature and relative humidity of the air in cowsheds and milking parlours of two dairy farms described in Materials and Methods are presented in Table 1. The results of this measurement show that the average air temperatures in both cowsheds CS1 and CS2 were lower than average external temperature. Thanks to the lower relative humidity of air in the cowshed CS1 is average calculated THI in this cowshed lower than in cowshed CS2.

Table 1. Average values and standard deviation of the air temperature t, relative humidity RH and THI in cattle houses of two dairy farms (the first dairy farm: CS1 modern cowshed and MP1 milking parlour; the second dairy farm: CS2 old cowshed and MP2 milking parlour) and outside in meteorological station during the long-time measurements

Parameter	t	RH	THI
Building	°C ± SD	% ± SD	- ± SD
External	27.3 ± 3.1	45.9 ± 14.2	73.4 ± 3.3
CS1	26.7 ± 4.0	47.0 ± 19.7	72.5 ± 2.6
MP1	26.7 ± 1.3	58.5 ± 8.2	74.9 ± 1.7
CS2	27.1 ± 1.7	50.5 ± 9.9	74.3 ± 1.3
MP2	27.2 ± 1.9	50.7 ± 10.1	74.4 ± 1.5

SD – Standard deviation.

Rather important are also changes of indoor temperatures during the hot days. The course of the air temperature and relative humidity of air during the whole long-time measurement is in Figs 3 and 4.

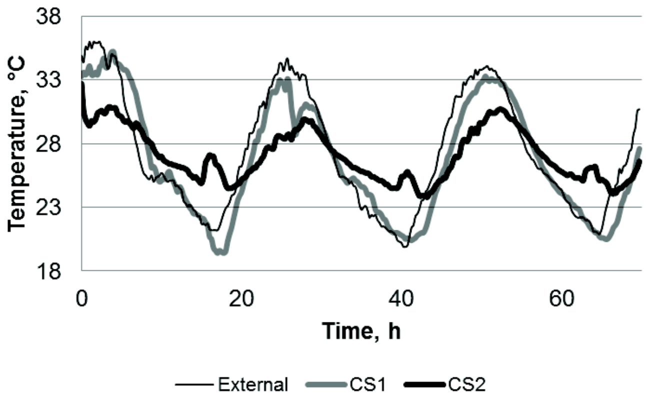

Figure 3. The course of the air temperature outside and inside the cowsheds CS1 and CS2.

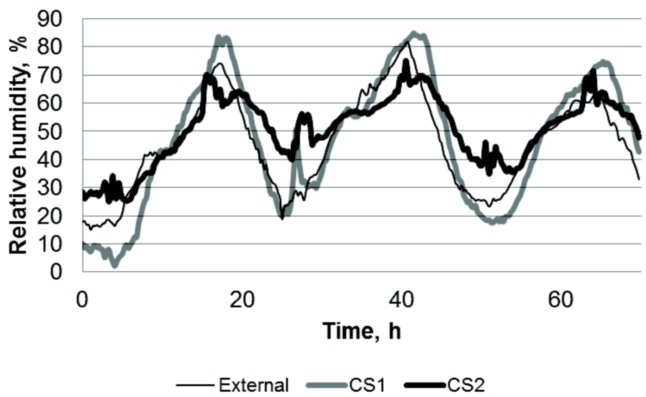

Figure 4. The course of the air relative humidity outside and inside the cowsheds CS1 and CS2.

The courses of relative humidity correspond to the internal temperature in halls and to the changes in external and internal environment. As in other farms with similar technological equipment, the air moisture does not cause major problems in terms of microclimatic comfort during the hot summer. Recommended maximum relative humidity 80% was not exceeded.

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Results of linear regression expressing dependence of internal temperatures on outside temperatures in the cowsheds CS1 and CS2 are presented in Fig. 5. According to the course of calculated equations of both lines is gradient (slope) of line (tangent line) 0.9164 (cowshed CS1) significantly higher than gradient of line 0.3525 (cowshed CS2). This implies that the internal temperature in the cowshed CS1 is more influenced by the outside air temperature than in the cowshed CS2.

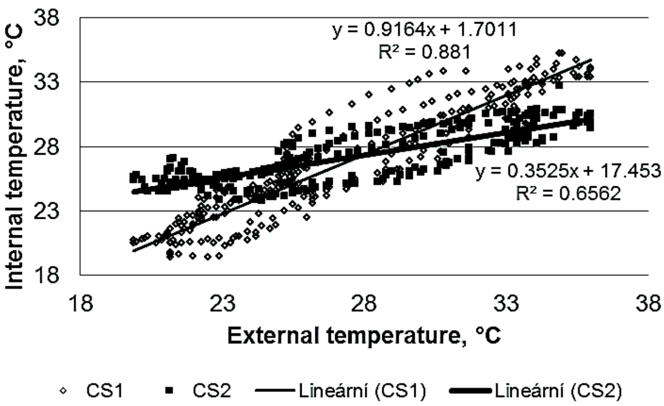

Figure 5. The linear regression of internal temperatures on outside temperatures in the cowsheds CS1 and CS2.

Correlation between internal and external temperatures is lower especially in the case of cowshed CS2 because the indoor air temperature changes are influenced (delayed and reduced) by the mass of constructions. It means that massive construction dampens the size of changes of inside temperature both in terms of amplitude and in terms of response speed to changes of outside temperature.

Rather interesting and important is therefore the comparison of oscillation amplitude A of external and internal air temperatures in Table 2. It also shows a reduction of amplitude of temperature oscillation A_R calculated as a difference between external and internal amplitudes and expressed also as a percentage of amplitude fluctuation A_{RP} of outside air temperature.

Based on the results of registered measurements of external and internal air temperatures a phase shift of the temperature oscillations are calculated, expressed as a time delay ψ_R of rise of the internal temperature behind external temperature rise and time delay of drop of internal temperature ψ_D behind external temperature drop. The results are also shown in Table 2.

Table 2. Average values of oscillation amplitude A of external and internal air temperatures, reduction of amplitude of temperature oscillation A_R and A_{RP}, time delay of rise of internal temperature ψ_R behind external temperature rise and time delay of drop of internal temperature ψ_D behind external temperature drop in the cowshed CS1 and in the cowshed CS2

Parameter	A	A_R	A_{RP}	ψ_R	ψ_D
Building	K	K	%	h	h
External	14.5	-	-	-	-
CS1	13.3	1.2	91.7	1.1	0.5
CS2	6.2	8.3	42.4	2.8	3.3

Average values and standard deviation of the globe temperature, internal air temperature, relative humidity concentration of CO_2, THI and BGHI in cowsheds CS1 and CS2 during the short-time measurements are presented in Table 3.

Table 3. Average values and standard deviation of globe temperature t_g, air temperature t, relative humidity RH, concentration of CO_2, THI and BGHI in cattle houses of two dairy farms (the first dairy farm: CS1 modern cowshed, and the second dairy farm: CS2 old cowshed) and outside in meteorological station during the short-time measurements

Place of measurement	t_g	t	RH	CO_2	THI	BGHI
-	°C ± SD	°C ± SD	% ± SD	% ± SD	- ± SD	- ± SD
External CS1	-	32.4 ± 0.1	21.7 ± 0.1	0.033 ± 0	76.2 ± 0.1	-
CS1	31.3 ± 0	30.7 ± 0.1	27.2 ± 0.1	0.034 ± 0	75.4 ± 0.1	76.1 ± 0.0
External CS2	-	35.8 ± 0.2	16.5 ± 0.2	0.033 ± 0	78.6 ± 0.1	-
CS2	30.6 ± 0	30.7 ± 0.1	30.2 ± 0.4	0.035 ± 0	75.9 ± 0.1	75.7 ± 0.1

SD – Standard deviation.

The results of short-time measurements confirm and develop more the results of long-time measurements just during the very hot period of summer day. There is a very positive effect of massive construction of cowshed CS2, which reduced inside temperatures during the highest outside temperatures. Calculated THI values are in both cowsheds lower than THI calculated from external data.

The external temperatures, under which the cowshed CS2 was measured (t = 35.8 °C) were more difficult than in the cowshed CS1 (t = 32.4 °C), nevertheless, the internal temperatures were the same (t = 30.7 °C) in both cowsheds. The positive influence of massive construction reflects the level of average t_g and therefore also calculated BGHI were lower in massive cowshed CS2 than in the modern cowshed CS1.

The results of CO_2 concentrations in cowsheds CS1 and CS2 presented in Table 3 are not surprising. The recommended maximum concentration of CO_2 of 0.20% was not exceeded in any house, as it was measured in the summer season with completely opened window, doors and other ventilation openings to maximum ventilation. Slightly higher concentrations of CO_2 in the cowshed CS2 is due to smaller volume of the internal space of cowshed and more difficult conditions for natural ventilation.

CONCLUSIONS

The results of measurements in cowsheds show that massive buildings better reduce external heat load by reduction of amplitude variation and by time shift of internal temperature.

Reduced oscillation of internal temperatures is important especially during the shorter-term variations of outdoor temperatures, because the inner part of the building does not warm up significantly. This is reflected primarily in animal houses with smaller biological loads and with lower intensity of ventilation e.g. in buildings for cattle housing.

The time shift caused by heat accumulation in the massive construction helps to overcome the high afternoon temperatures, which reflects a time shift in the increase of indoor air temperature. Due to the reduction in the amplitude of air temperature the indoor air temperature does not reach the maximum temperature of the outside air.

Natural ventilation is reflected with the opposite effect compared to the standard, because in this case the outside temperature is higher than the internal and the direction of air flows in inlets and outlets are opposite.

The principles of heat accumulation in massive constructions should be used in some modern buildings in combination with other principles of passive air conditioning.

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