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Influence of hygrothermal conditions on milk production in a free stall barn during hot weather*

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Presented are results of a study on the influence of air temperature and humidity on milk production by 174 Holstein-Friesian cows kept in a free stall barn. Occurrence of heat stress in three technological groups of cows with help of temperature-humidity index (THI) was specified. The result of heat stress was a decrease in milk yield. There was a strong correlation found (P=0.05) between minimum THI, temperature and milk yield. Delay of decrease in milk production as related to maximum temperature (T_{MAX}) in most cases was 2 days (P=0.05). Significant differences were shown between THI average hourly values (from 1 to 6 units) in particular areas of the barn when the average daily THI >68. Duration of total air temperature exceed 21°C in each technological group was investigated. It was concluded that the number of hours above the critical temperature for the cows in group 1 was 90 and 42-44 for the remaining groups, which resulted in the largest decrease in milk yield in group 1. The obtained results indicate the need to evaluate the microclimate parameters in several specific places related to the existence in the barn technological groups. Predicting the risk of heat stress should take into account the zoning in the barns related to variations of temperature and humidity conditions. This will enable the selection of appropriate functional, utility and technical solutions to maintain optimum welfare of cows in free stall barn.

KEY WORDS: air humidity / air temperature / cows / hot weather / milk production / temperature-humidity index

The purpose of dairy farming is to achieve the highest milk yield of cows maintaining the welfare of the animals by, for example, keeping suitable microclimate of the building [Albright and Timmons 1984, Cook *et al*. 2005].

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Temperature from -0.5 to +20°C insignificantly affects milk production [West 2003]. However, a temperature achieving the so-called critical temperature at the level of 25-26°C [West 2003] or 24-27°C [Broucek *et al*. 2009] may reduce milk production and adversely affect the fertility of cows [St. Pierre *et al.* 2003]. It also leads to deterioration of the chemical composition of milk [Bouraoui *et al.* 2002].

High productivity of dairy cattle contributes to the production of large quantities of body heat that must be dismissed out of the body. However, in high air temperature and relative humidity, this process is hindered. As a result, animal body temperature rises excessively, leading to impaired thermoregulation and heat stress, which is easily to observed in hematological blood tests [Radkowska and Herbut 2014]. To reduce heat production, cows consume less feed, which in turn decreases milk production [Lautner and Miller 2003]. The negative effect is also in decreased cows activity, which in optimum air temperature depends mainly on lactation stage, space allowance, free-stall design and bedding [Broucek *et al*. 2013].

Heat stress in cattle is a problem faced by herdsmen around the world. Apart from air temperature and air relative humidity, it is conditioned by air movement velocity and the intensity of solar radiation in unshaded areas of the barn [Kadzere *et al*. 2002, Herbut and Angrecka 2003].

The most popular index describing heat stress is THI. It was initially used to evaluate thermal comfort for people [Thom 1959]. However, it was quickly recognized that the index can be used for a variety of animal species [Lendelova and Botto 2011]. For the past 50 years, the THI has undergone various modifications with regards to parameters corresponding to cattle heat stress [Bohmanova *et al*. 2007]. The one of most commonly used THI formula has been developed by the National Research Council [1971] taking into consideration dry-bulb temperature and relative air humidity.

Material and methods

The aim of this study was to define the influence of air temperature and humidity on milk production during hot weather in the three areas of a free stall barn occupied by technological groups of cows differing in milk production level.

The measurements were conducted during summer in the years 2011 and 2012, in a modernized free stall barn for 174 Holstein-Friesian cows. The building of 1580 m^2 usable floor area was located in Kobylany, the Malopolska Province, Poland (N: 50° 8’ 59” E: 19° 45’ 12”) oriented along the east-west axis. The index of usable floor area for group 1, 2 and 3 was 8.3, 7.5 and 6.6 $m^2 \cdot animal^{-1}$, respectively.

The total mixed feed ration was supplied twice a day. Feed was allowed throughout the 24-hour period, except milking. The energy content of feed ration for the cows in group 1 was 7.05, in group 2 – 6.54 and in group 3 – 6.31 MJ NEL/kg DM. The composition of the TMR remained throughout the year and included corn silage, haylage, hay, corn grain, wheat, concentrate mixture, and mineral and energetic components. Feed ration included the factors for maintenance, growth, reproduction and lactation. Manure was removed mechanically twice a day.

Temperature and humidity measurements were conducted every 6 minute with the LB-710 sensors produced by LABEL. The sensors were placed in the occupied zone at the height of 1.0 m. The first measurement point was located in the shaded part of the barn, occupied by the most productive technological group 1 (average milk yield of 31.5 kg). The second measurement point was located in the part of the barn exposed to sunlight, occupied by group 2 (average milk yield of 21.6 kg). The third measurement point was located at the northern part in the least productive group (average milk yield 12.7 kg). Each technological group consisted of 58 cows (Fig. 1).

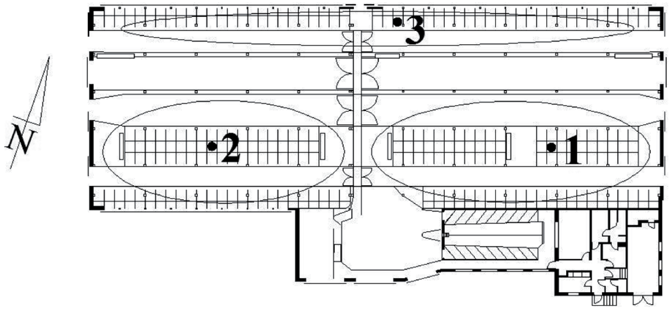

Fig. 1. The distribution of measurement points inside the barn: 1 – group 1; 2 – group 2; 3 – group 3.

The information regarding daily milk yield was obtained from the dairy management software AFIMILK.

Air temperature, relative air humidity, THI and milk yield were analysed in three groups in selected period by Pearson correlation coefficients with use of Statistica (version 10.0). Data are considered significant at P = 0.05.

Calculation of THI (temperature-humidity index) according to the National Research Council formula [1971] was based on measurement data:

$$THI = (1.8 \times T_{DB} + 32) - [0.55 - 0.0055 \times RH) \times (1.8 \times T_{DB} - 26),$$

where:

T_{DB} – dry-bulb temperature °C;

RH – relative humidity %.

Minimum (THI_{MIN}) and maximum (THI_{MAX}), daily and hourly THI indexes calculated for selected study periods were referred to average daily milk yield of each technological group. Minimum daily index THI_{MIN} was calculated on the basis of minimum daily T_{DB} and maximum daily RH, whilst the maximum THI_{MAX} on the basis of maximum daily T_{DB} and minimum daily RH [Vitali *et al.* 2009].

Out of the time span including two summer seasons, four shorter periods were selected for analysis (June 14 – 24, 2012; June 27 – July 17, 2012; July 24t – August 08, 2012; August 18 – 27, 2012). They included a few days before the hot weather started, the period when temperature was >25°C and a few days after the hot weather stopped.

Results and discussion

Minimum, maximum and average temperatures as well as relative humidity values during hot weather periods in 2012 are presented in Table 1.

Table 1. Temperature and relative humidity values in the researched periods

Time period	Area of group	Air temperature (ºC)			Relative air humidity (%)		
		MIN	MAX	AV	MIN	MAX	AV
14.06 - 24.06	1	14.6	30.0	23.4	40.1	88.0	67.7
	2	14.1	31.6	23.5	38.0	91.3	68.2
	3	13.3	29.9	24.0	46.2	88.0	67.1
27.06 - 17.07	1	18.8	33.2	22.9	35.0	87.1	67.2
	2	16.6	35.2	22.4	32.5	93.0	68.8
	3	16.1	33.4	23.7	34.9	92.9	68.7
24.07 - 08.08	1	16.6	33.0	23.7	35.3	91.4	65.0
	2	15.6	35.3	23.5	26.6	93.0	65.5
	3	16.0	33.2	23.4	35.8	92.4	68.5
18.08 - 27.08	1	16.1	31.7	23.1	37.6	87.3	65.1
	2	14.3	33.5	22.8	28.1	91.5	64.5
	3	15.2	32.1	23.1	35.1	87.4	64.5

MIN – minimum values of temperature and relative humidity.
MAX – maximum values of temperature and relative humidity.
AV – average values of temperature and relative humidity.

Detailed analysis performed for the most representative period of June 27 – July 17, 2012, confirmed with the highest statistical significance amongst all the analysed research periods.

Cows from the first technological group were exposed to high air temperature a day and night, because nightly temperature falls below 21°C were short-term, not exceeding 4 hours. Temperature distribution in group 2 was different. Considering Polish climatic conditions, daily air temperature was relatively high (above 34°C), whilst at night it fell below 21°C for 5 to 8 hours. In group 3, night temperature below 21°C usually lasted for 5 to 10 hours (Fig. 2).

In all technological groups, RH was at a similar level but in group 2, the RH scope was the highest.

The highest milk yield variations in the studied period were observed in group 1, while the lowest – in group 3. The short period of lower temperatures which occurred at night of July 11/12 resulted in a noticeable increase in milk production by 2 kg two days later. In group 2, the cooler period caused a small increase in milk yield by only 0.5 $kg \cdot d^{-1}$ whilst in group 3 this cooling did not influence the level of milk production.

The important characteristic for the analysed barn was that the period of continuous temperatures T_{DB} exceeding 21°C varied for different technological groups. For group 1 this period was 90 hours, for group 2 – 44 hours and for group 3 – 42 hours.

Values of THI at night were greater than those during the day. The daily amplitude of air temperature and THI in the area occupied by group 1 was greater than in the other technological groups (Fig. 3). These differences were mainly due to the fact that

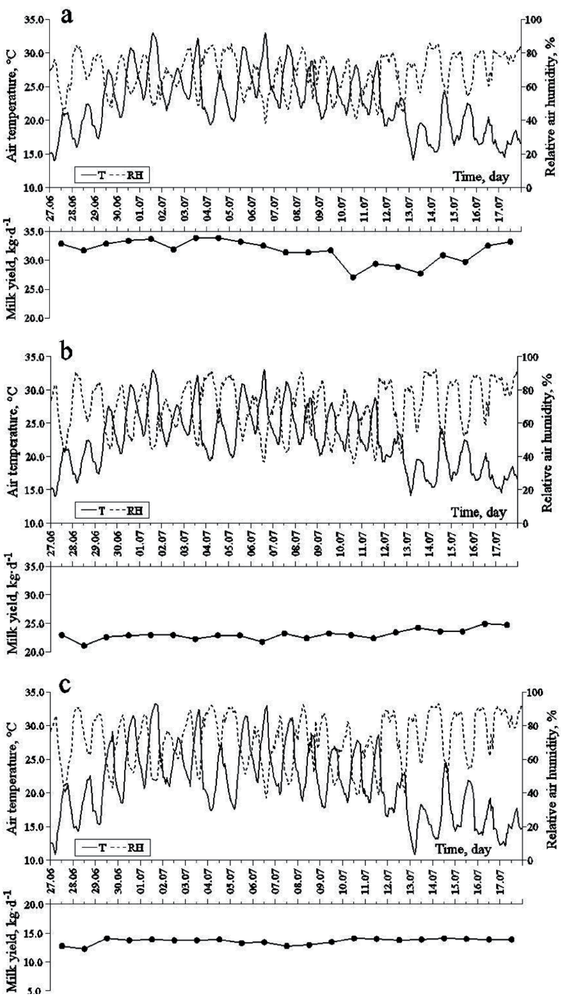

Fig. 2. Temperature (T) and relative humidity (RH) distribution (upper chart) and milk production (lower chart) in the period June 27 – July 16, 2012: a – for group 1; b – for group 2; c – for group 3.

zone 2 was exposed to sunlight and zone 3 was shadowed. Also, these two zones had the possibility of direct air exchange with the surrounding areas, which was impossible in the case of group 1.

Results of temperature measurements and THI calculations were referred to milk yield in particular technological groups. Statistical analysis for group 1 (P<0.05) revealed that milk yield depended mostly on average air temperature (T_{AV}) (r = -0.82). Lower correlation was observed for minimum (T_{MIN}) and maximum (T_{MAX}) temperature (-0.75 to -0.70).

In group 3, the correlation between milk yield and temperature was weaker. For average air temperature it was r = -0.63, and for minimum temperature: r = -0.62. The correlation between maximum air temperature and milk yield in group 2 was r = -0.52 for P<0.05 (Fig. 4).

In group 3, the correlation between T_{MIN} and milk yield was r = -0.47 (P<0.05); for T_{AV} it was r = -0.49 (P<0.04) and for T_{MAX} it was r = -0.52 (P<0.03).

The correlation between relative air humidity and milk yield was very low (r = -0.10 to -0.30).

Significant correlation of THI_{MIN} index with milk yield both for group 1 (r = -0.77) and group 2 (r = -0.81), with P<0.05 was showed. For group 3, the correlation coefficient was -0.44 (P<0.11). The correlation between THI_{MAX} and milk yield for group 1 was significant at the level of r = -0.70 (P<0.05) and for group 3 at r = -0.49 (P<0.09) – Figure 5.

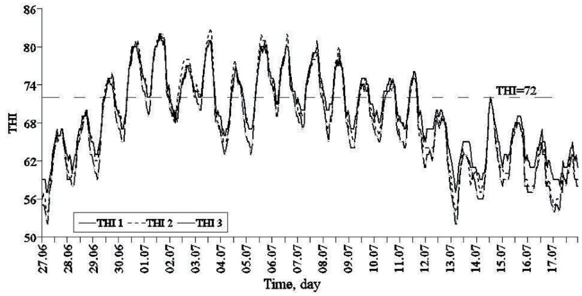

Fig. 3. The values of THI indexes in the period June 27 - July 16, 2012.

In the discussed period, the change in average daily milk yield occurred with a certain delay with respect to air temperature pattern and THI. The most significant decrease in daily milk yield in group 1 was 4.7 kg (July 10); in group 2 it was 1.2 kg (July 6) and in group 3 it was 0.8 kg (July 7).

Kadzere *et al*. [2002] concluded that THI <70 points to the lack of heat stress, THI values of 75-78 point to heat stress, and THI >78 means serious threat to cow welfare. Most commonly, it is assumed that heat stress occurs when THI values exceed 72 since milk production begins to decrease [Armstrong 1994, Ravagnolo and Misztal 2002, West *et al.* 2003, Broucek *et al*. 2009, Akyuz *et al*. 2010]. According to Carter *et al*. [2011], cows suffer from heat stress if the mean daily THI exceeds 68, when the minimum daily THI is greater than 65 or both. Hahn *et al*. [2009] claimed that THI border value also depends on milk production level. For highly productive cattle, heat stress begins when THI = 72, whilst 74 is the border value for less productive cattle.

During the analysed hot weather conditions in southern Poland, daily THI values in group 2 were greater from these in group 1 by three units. In turn, in group 3 these were higher by 1 unit. At night, THI values for group 1 exceeded the values for the remaining groups by 3 to 6 units. The main reason was that the cows in group 1 occupied an area in the vicinity of an internal partition wall, which served as protection against solar radiation during the day and against the inflow of cooler air during the night.

Variations of THI for all technological groups points to significant differences in temperature and humidity conditions in particular areas of the barn. Preliminary assessment for particular areas occupied by cows in the context of heat stress risks should serve as the basis for developing future functional solutions and distributing air mixers [Herbut and Angrecka 2012]. According to the authors, the measurements of air parameters in one spot of the barn, which was presented in the research of West *et al.* [2003] and Dikmen and Hansen [2008] cannot reflect the conditions for the entire barn and consequently make it more difficult to manage the risk of heat stress.

Heat stress that occurred during the analysed periods of hot weather resulted in decreased milk yield registered by the system.

The delay in milk yield decrease with respect to T_{MAX} in most cases equaled 2 days and only in one case it was 3 days, which turned out to be aligned with the results of

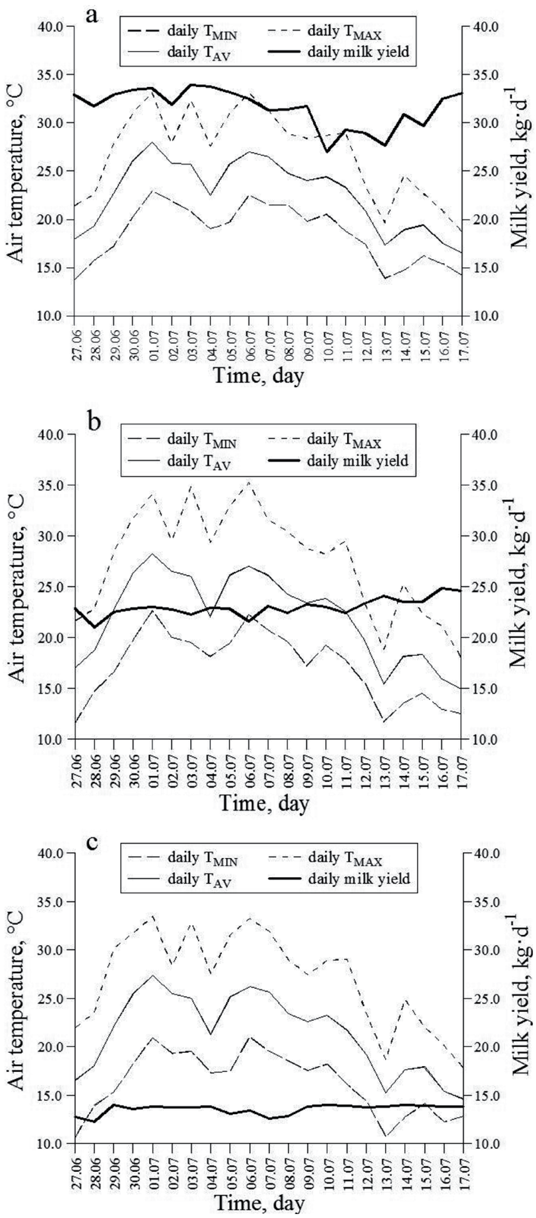

Fig. 4. Minimum (daily T_{MIN}), average (daily T_{AV}) and maximum (daily T_{MAX}) temperatures against milk production levels in the period June 27 – July 16, 2012: a - group 1; b - group 2; c – group 3.

West *et al.* [2003] and Spiers *et al.* [2004].

At the time when the study was performed, average daily THI was >68, and during hot weather (in the Polish climate) they even reached the level of 75. Minimum daily THI differed depending on the area occupied by cows. In group 1 it was most often above 65 while in group 2 it varied between 60 and 67; in group 3 the range was 59 to 70.

According to Linvill and Pardue [1992], what significantly influences the potential decrease in milk production during the 4-day hot weather period is the total number of hours when THI>74 and THI>80 on the day before milk yield fell. In the presented period, THI values did not exceed 80 on the day before milk production decreased. In the course of 4 days before the milk production decrease was registered by the system, the number of hours with THI>74 was approx 30 for groups 1 and 2. In group 3 significant decrease in milk production did not occur at all.

The analysis of correlation between THI_{MAX} and milk production in groups 1 and 2 revealed that it was weaker than that between THI_{MIN} and milk production. Therefore, the obtained results contradict the conclusions of Ravagnolo and Misztal [2000], who state that THI_{MAX} is the best indicator for heat stress in cattle.

During hot weather periods, cows from group 1 suffered from heat stress even for20 hours per

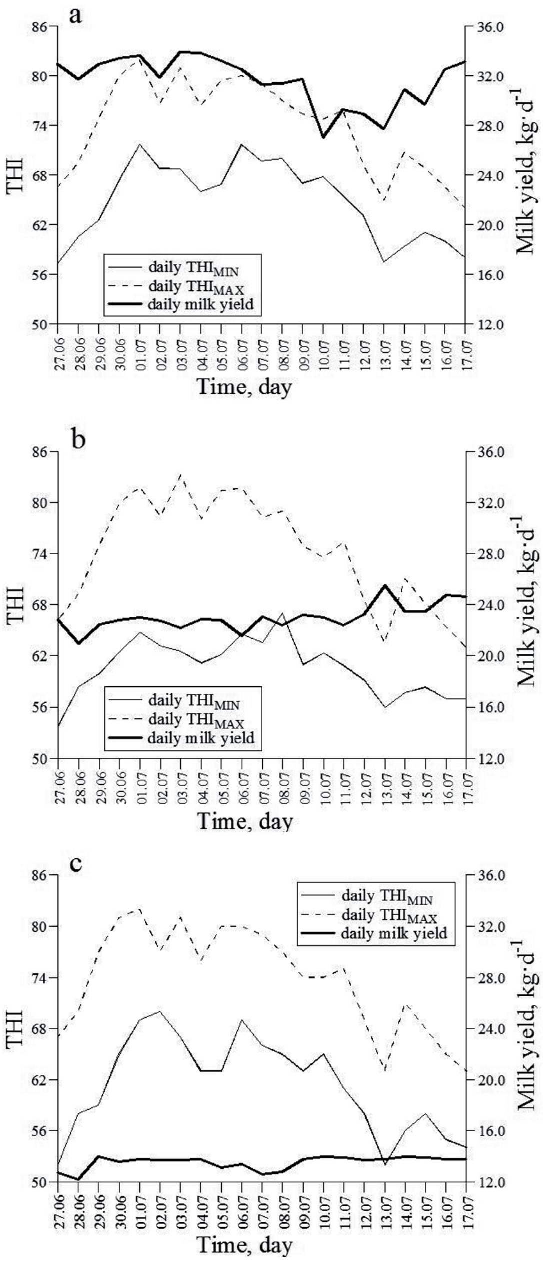

Fig. 5. Minimum (daily THI_{MIN}) and maximum (daily THI_{MAX}) THI values against milk production levels: a – group 1; b – group 2; c – group 3.

day; this was mainly due to the fact that the temperature was very high both during the day and at night. The lack of night cooling for 3 consecutive nights (July 6-8) and a short, only 4-hour, cooler period at the night of July 9 resulted in milk production decrease by 5 kg on July 10. In group 2, the risk of heat stress was observed during the day for approx 12 hours. At night, air temperature below 21°C was observed for 6 to 8 hours. Following the assumptions of Igono *et al.* [1992], it was concluded that the risk of heat stress in cattle does not occur when air temperature falls below 21°C by at least 3-6 hours per day. It was also concluded that the number of hours with increased temperature was 90 in group 1 and 42-44 in the two remaining groups.

The conclusions of Igono *et al.* [1992] also point to the need of cooling the air temperature to the level below 21°C for at least 6 hours during the day. In the August of 2012, when the temperature at night ranged between 18 and 21°C for as long as 8 hours, the decrease in milk yield was not registered, despite the fact that daily mean temperature exceeded 25°C for at least 11 hours. Ensuring such conditions would limit the risks of heat stress. In the case of the studied building, it can be assumed that during hot weather cows from group 1 should be cooled all the time; in group 2, the cooling should be ensured only during the day; whilst in group 3, cooling was not necessary. A good solution would also be location of the most efficient technological groups in the zones of the most favourable hygrothermal condition.

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