Animal Science Papers and Reports vol. 30 (2012) no. 4, 363-372
Institute of Genetics and Animal Breeding, Jastrzębiec, Poland

Forming of temperature-humidity index (THI) and milk production of cows in the free-stall barn during the period of summer heat*

Piotr Herbut, Sabina Angrecka**

Department of Rural Building, University of Agriculture,
30-059 Cracov, Al. Mickiewicza 24/28, Poland

(Received March 19, 2012; accepted September 20, 2012)

Evaluated were changes of temperature and relative air humidity inside a free-stall barn affecting the welfare of cows of three technological groups during a hot summer. The effects of selected microclimate parameters of the barn have been assessed based on the THI (temperature-humidity index) in relation to milk production. The research revealed that the animals suffered from thermal stress which resulted in decreased milk production in particular groups. The paper presents information about percentage values of this decrease and time needed to regain the original state. It also points out the need to determine THI not only for the entire barn but also for its various zones occupied by particular technological groups of cows with different levels of milk production. The authors highlight that the THI index is quite a useful tool for predicting thermal stress in particular sections of the barn. Yet, it is necessary to improve the methodology of THI calculation in order to include more microclimate elements, mainly air movement.

KEYWORDS: air humidity / air temperature /cattle / free-stall barn / dairy cows / milk production / THI index

One of the most important challenges in modern barns is to maintain appropriate microclimate, *i.e.* sufficient air temperature, humidity, air flow velocity, low pollution (with dust particles and microorganisms) and low content of gases. Those factors definitely contribute to the proper development and maintenance of cattle welfare, which influences milk production in a significant way.

*Financed from grant No. N311 401639 of the Ministry of Science and Higher Education, Poland
**Corresponding autor: p.herbut@ur.krakow.pl

Cattle are able to adapt well to changeable temperature conditions. The temperature scope from -0.5 to +20°C has little effect on milk production; critical maximum temperature for cows is assumed to be at the level of 25-26°C [West 2003] or 24-27°C [Broucek 2009]. Different values are attributed to the fact that operative temperature for cows is influenced by a number of factors, such as pregnancy, milk production, air movement around the animal, relative air humidity and the degree of acclimatization [Broucek 2009].

The interrelation between air temperature and humidity is important from the point of view of animal welfare and cattle production profitability. Low temperature accompanied with high humidity may be very unfavourable. When air temperature is low, cows emit more heat to the environment. At the same time, they increase heat production and consume more feed in order to compensate body energy losses. When the animal is overheated, high humidity may lead to infections of respiratory tract or udder. On the other hand, high temperature and low relative air humidity may dehydrate mucous membranes thus increasing vulnerability to viruses and bacteria [Romaniuk *et al*. 2005].

High milk production results in increased production of heat by cows. The surplus of produced heat needs to be emitted to the surrounding air. However, this is difficult when the air temperature is already high and relative air humidity is elevated. As a result, body temperature of animals increases. Consequently, we run the risk of causing thermal stress. In order to prevent overheating, cows consume less feed which leads to lower milk production [West 2003]. Moreover, thermal stress negatively influences hormone management and cow fertility [St. Pierre 2004 *et al*. 2003, Jaśkowski *et al*. 2005, Jóźwik *et al*. 2012].

The appearance of the concept of thermal stress led to elaboration of index which would reflect when thermal stress may occur. The most popular here is thermal-humidity index (THI). A number of calculation methods have been developed over the years to establish THI. Depending on the author, calculation formulae are based on temperature (dry-bulb or wet-bulb thermometer), air humidity (relative or absolute). In the equations by Yousef [1985] and Bianca [1962], dew point temperature is used instead of relative air humidity [Bohmanova *et al*. 2007, Dikmen and Hansen 2008].

The aim of this study was to determine temperature and humidity conditions during heat waves in selected areas of a free-stall barn occupied by three technological groups of cows.

After analysing the obtained results and relating them to the THI index, it was possible to determine zones in the barn where cow welfare decreased. THI values were compared to milk production levels in particular technological groups.

Material and methods

The measurements were conducted in a modernized Fermbet-type free-stall barn for 174 Holstein-Friesian cows divided into three technological groups (each after 58 cows). Average annual milk production for 2011 for individual technological groups was for group 1-32 kg, for group 2-21 kg and for group 3-12 kg. The free-stall barn was situated in the village of Kobylany, the Malopolska region. The size of the main hall with stalls was 67.0 x 24.5 m. The milking parlour (fishbone, 2x10), holding area, collection area, social room and storage were all situated in the south-eastern extension of the building.

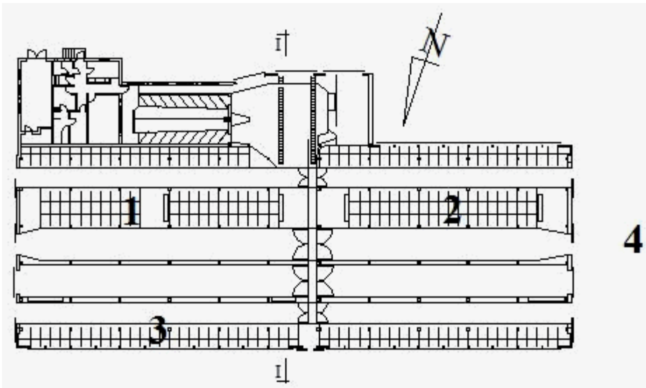

Fig. 1. The distribution of measurement points inside the barn: 1– technological group 1 (with highest milk production), 2 – technological group 2 (with medium milk production), 3 – technological group 3 (with low milk production), 4 – meteorological mast.

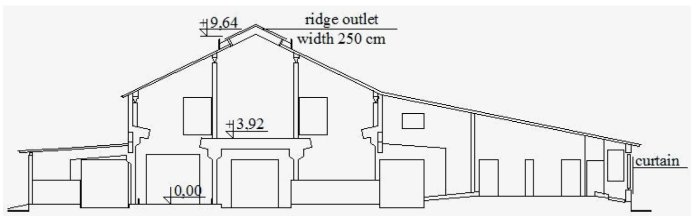

Fig. 2. Cross-section I-I.

The ventilation system included outlet ridge skylights and inlet openings with curtains in longitudinal walls. The curtains were lowered at the time when the measurements were taken (Fig. 2).

The study was conducted during three summer months of year 2011 (July, August, and September). Temperature and relative humidity were measured with 6-minute intervals in three selected points inside and one point outside the barn. Inside the barn, the sensors were placed in the occupied zone, 1 m above the floor (Fig. 1).

Measuring was conducted with the integrated temperature and humidity sensors LB-710 (Label, Poland). Data of milk production were obtained from dairy management records software (2 milking rounds per day).

Measurement results were presented based upon the THI index, according to the following National Research Council formula [NRC 1971]:

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

where:

T_{db} – dry bulb temperature (°C);

RH – relative humidity (%).

The authors recorded a diversified range of temperature and humidity values in the measuring period. It was assumed that 20°C will be considered threshold temperature for heat wave periods. Temperatures equal or exceeding this value were recorded between 13 August and 13 September and this period was considered for further analysis. Obtained temperature and humidity values in the selected time span were compared to average daily milk production in particular technological groups. For that purpose, minimum and maximum daily average THI index was established in each of the occupied zones. Maximum daily THI was determined based on maximum air temperature and minimum air humidity on a given day. Minimum daily THI was determined based on minimum air temperature and maximum air humidity on a given day [Vitali *et al*. 2009, St. Pierre 2004 *et al*. 2003].

It was also noted that during the days 22-27 August (6 days) air temperature exceeded 27°C. THI index was calculated as average hourly result for each technological group occupying the measurement area.

Results and discussion

Based on the conducted measurements, temperature and relative humidity charts were developed for 3 measurement points situated in three areas occupied by technological groups. During the presented research period, air temperature and relative humidity in the zone occupied by the first group of cows (with the highest milk production) – Figure 3 – were lower by 2-4°C than in zones 2 and 3 as well as in the measurement point situated outside the building (Fig. 4-6). At night, air temperature in zone 1 was higher by 2-3°C than in zones 2 and 3 and approximately by 4°C higher than outside. Range of temperature inside the barn for the six days of hot period was from 16°C to 32°C and outside from 15.5°C to 33°C.

Similar differences between particular zones could also be observed for relative air humidity values. Relative air humidity in zone 1 (Fig. 3.) was at the level of 44-88%. In turn, humidity in zone 2 (Fig. 4) ranged between 35 and 90%. For zone 3 (Fig. 5), humidity varied between 40 and 92%, whilst outside, in measuring point 4, it did not exceed the range 36-96% (Fig. 6).

Fig. 7 presents changes in THI in the studied zones during heat waves. In the case of the most productive technological group (zone 1), only insignificant variations were noted. At night THI occurred higher (by 2 to 5 units) than in other zones; while during the day THI was lower than THI in the other two zones. Most significant THI variations occurred in the zone occupied by the least productive technological group.

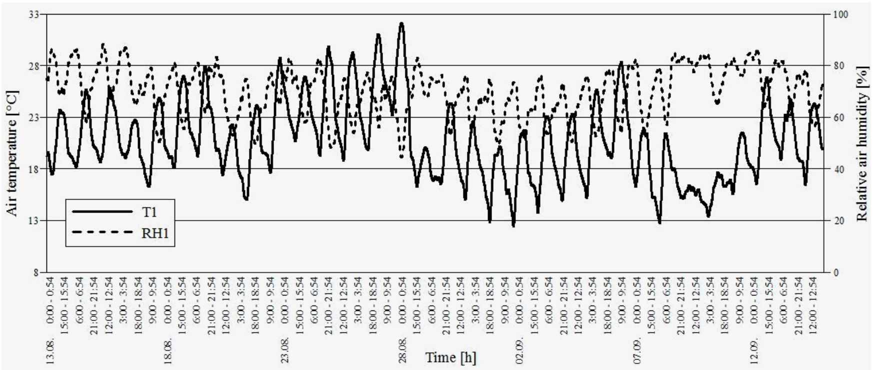

Fig. 3. Air temperature and relative air humidity in measurement point 1 situated in the zone occupied by the most productive technological group of cows (group 1).

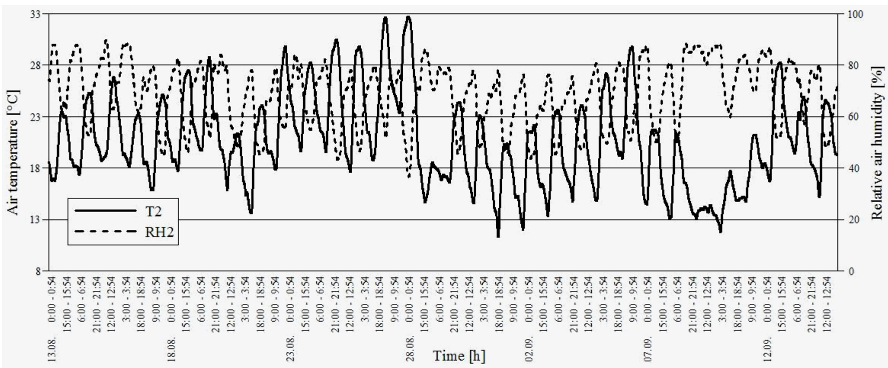

Fig. 4. Air temperature and relative air humidity in measurement point 2 situated in the zone occupied by the technological group with medium production level (group 2).

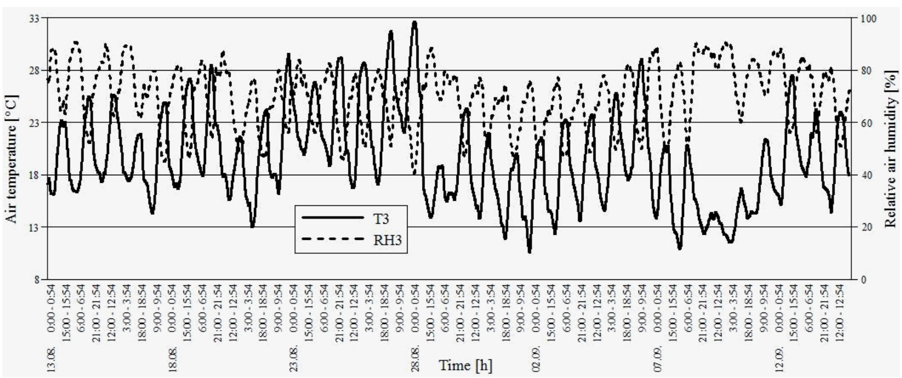

Fig. 5. Air temperature and relative air humidity in measurement point 3 situated in the zone occupied by the least productive technological group of cows (group 3).

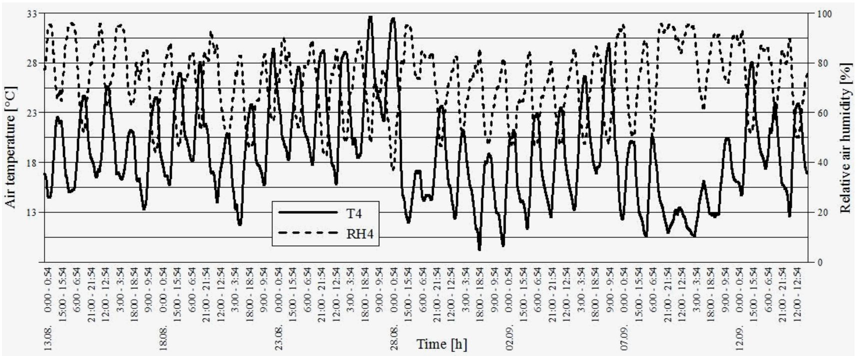

Fig. 6. Air temperature and relative air humidity in measurement point 4 – meteorogical mast.

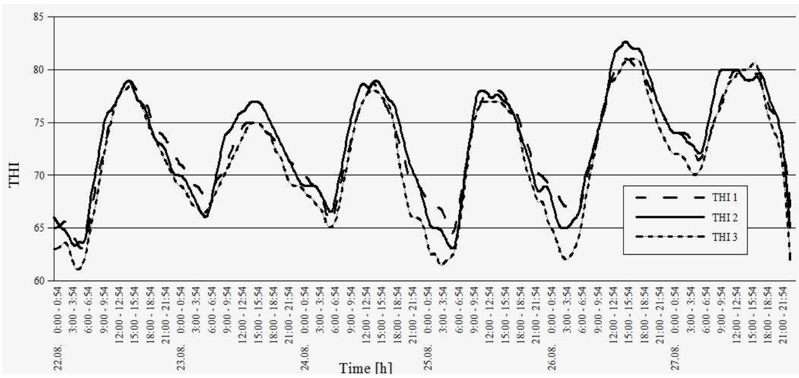

Fig. 7. Average hourly THI values calculated for zones 1, 2 and 3 between 22 and 27 August 2011.

Based on THI average hourly values, one could conclude that cows from the most productive technological group (1) experienced most favourable welfare conditions between 7 am and 6 pm. The reason for that is the localization of their living area along the longitudinal wall (Fig. 1), which protected from excessive temperature increase during the day and humidity increase at night. The wall also prevented temperature decrease at night and humidity decrease during the day. Lack of sudden temperature changes during the day is very favourable for the cattle. However, at night, the conditions in this part of the barn actually worsened, which could be noticed during the night of 26/27 August (Fig. 7), when the THI index did not fall below 71.

Cows from the other two groups were exposed to significant temperature and relative humidity variations in their living zones. These variations were mainly caused by the open longitudinal wall, which did not provide sufficient protection from outside conditions.

In order to verify the influence of changeable temperature and humidity conditions on milk production, prepared were charts of minimum and maximum daily THI and average daily production considering particular technological groups (Fig. 8-10). When the temperature and humidity conditions decreased during heat waves, milk

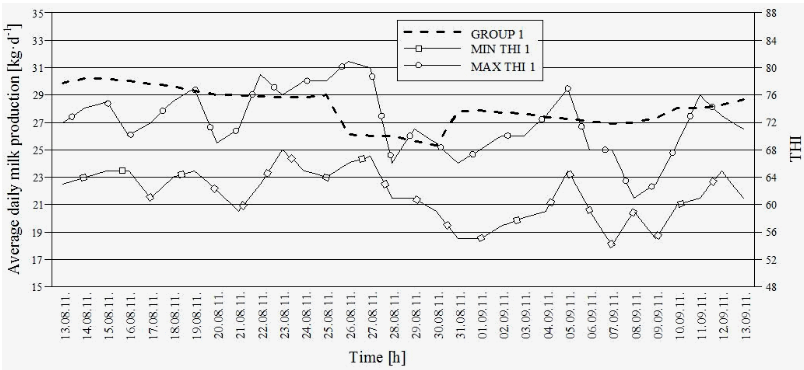

Fig. 8. Average daily milk production and minimum and maximum daily THI for group 1.

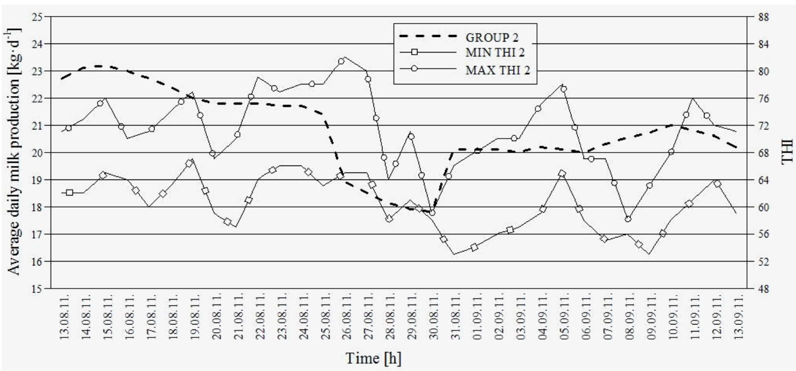

Fig. 9. Average daily milk production and minimum and maximum daily THI for group 2.

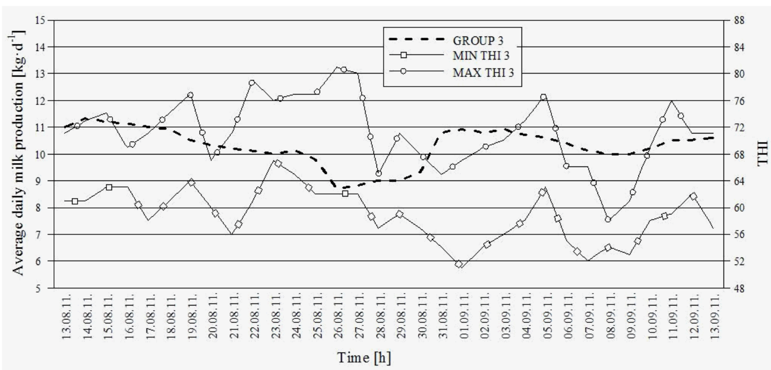

Fig. 10. Average daily milk production and minimum and maximum daily THI for group 3.

production dropped in all technological groups. Production decrease occurred 4 days after the start of high temperatures. Cows in groups 1 and 2 produced 3-4 kg milk less; cows in group 3 produced 1-2 kg less. Milk production returned to its original level only 4 days after the heat wave ended (Fig. 8-10).

Thermal stress is most often conditioned by air temperature, relative air humidity, solar radiation and air movement velocity [West *et al*. 2003].

According to Armstrong [1994], highly productive cows are very vulnerable to thermal stress. Berman [2005] concludes that with the increase of milk production from 35 to 45 kg·d^{-1}, the level of cattle vulnerability to high temperatures decreases by 5°C. The analysis of measurements conducted in Kobylany confirmed these statements and revealed that thermal stress and production decrease occurred in all three zones occupied by cattle.

Thermal stress can be expressed by means of THI. THI limit value is 72 [Armstrong 1994, Ravagnolo and Misztal 2000]. Anything above that value leads to first symptoms of thermal stress. According to Broucek [2009], THI value of 70-72 is like a warning before the thermal stress which is going to appear; milk production starts to decrease. It is recommended, therefore, to provide some cooling at such a situation. THI value of 72-78 may cause very serious risk to milk production and requires efficient, usually mechanical, ventilation. First production losses are visible when THI reaches the value of 72. However, the highest milk production decrease occurs when THI is in the range of 76-78. With THI exceeding 82, cooling is indispensable because such conditions may lead to death of animals [Broucek 2009]. Akyuz *et al*. [2010] distinguishes three levels of thermal stress depending on THI value: mild stress 72-79, moderate stress 79-89 and heavy stress >89. Similar ranges were presented by Armstrong [1994], who also stated that with THI value exceeding 98 animals die.

In this study, THI index calculated for the 6-day heat wave remained in the range 76-82. This leads to the conclusion that animals living in this barn experienced moderate thermal stress. On 26 and 27 August, THI value in all groups exceeded 80. Such a high result reveals that there was a risk to cows' lives [Broucek 2009, Vitali *et al*. 2009]. Also, it needs to be noted that the summer of 2011, when the research was conducted, was not a typical summer for the Polish climate because of relatively small number of hot days when compared to previous years.

THI values were also compared with average hourly temperature and humidity values, which helped to specify in what way microclimatic conditions inside the barn changed during the heat waves. Bouraoui *et al*. [2002] conducted one measurement during the day; West *et al.* [2003] determined temperature and relative air humidity values for 24-hour periods. Such research methodology does not reflect fully all the parameters because these depend on a number of factors and change significantly during the day.

Decrease of milk production was the most serious outcome of unfavourable temperature and humidity conditions inside the barn. Milk production started to drop on 26 August, that is 4 days after the first hot day. The delay was quite long, as production decrease is usually observed after 2 consecutive days of thermal stress [West 2003, Spiers *et al.* 2004]. According to the former, critical values for minimum and maximum THI amount to 64 and 76, respectively. In the present study these values have been exceeded significantly.

The increase of THI value in all of the researched zones by 8 units lead to production decrease of 0.36 kg per THI unit for the most productive technological group, 0.28 kg per THI unit for group 2 and 0.18 kg per THI unit for the least productive technological group. Ravagnolo and Misztal [2000] report milk production decrease of 0.2 kg per THI unit, which is similar to the results obtained in this study. West [2003] reported the loss of 0.88 kg milk per THI unit.

The highest production decrease expressed in kg milk per THI unit, was observed in the first technological group. Size of production decrease of the third technological group was the lowest so it could have been assumed that this group was localized in the most favourable part of the barn and therefore it avoided significant production losses. However, taking into consideration the size of production decrease compared to the results occurring before the heat waves, we obtain a different image. Milk production went down by 10% for the most productive technological group, by 11.5% for the average group and by 14% for the weakest group. This means that the highest production decrease was observed in zone 3. These results are, therefore, different from conclusions formulated by Armstrong [1994], who stated that cows producing most milk are also most vulnerable to production falls as a result of thermal stress.

In the studies conducted by West *et al*. [2003], Bouraoui *et al*. [2002] and Dikmen and Hansen [2008], parameter measurements were conducted in one spot inside the barn. The former two authors conducted measurements in the feeding area, whilst Dikmen and Hansen [2008] in the central point of the barn. Based on research conducted in the barn, we can conclude that temperature and humidity conditions are not identical for the entire building. In this study, differences between THI values in particular occupied zones were caused by specific shape and construction of the building: longitudinal wall next to zone 1 or open longitudinal walls in zones 2 and 3, but most of all geographical orientation. Even though the applied THI index did not take into consideration insolation and air movement inside the barn (which develop differently depending on how the building is situated in terms of geographical orientation), one could agree with Mader *et al.* [2006] who claim that supplementing the THI calculations with those two parameters would yield a fuller and more favourable picture of inside conditions. If insolation and air movement were considered in THI calculations, it would be possible to predict changes inside the barn more accurately. As a result, it would be possible to prevent thermal stress and production losses [Mader *et al*. 2006]. Defining THI values for particular technological groups and not for the entire barn would also make it possible to select more appropriate living areas for animals during heat waves. Additionally, this would help to determine requirements for new barns with appropriate ventilation systems, both in terms of technical construction and localization inside the building.

REFERENCES

1. AKYUZ A., BOYACI S., CAYLI A, 2010 – Determination of critical period for dairy cows using temperature humidity index. ***Journal of Animal and Veterinary Advances*** 9(13), 1824-1827.
2. ARMSTRONG D.V., 1994 – Heat Stress Interaction with Shade and Cooling. ***Journal of Dairy Science*** 77, 2044-2050.
3. BERMAN A., 2005 – Estimates of heat stress relief needs for Holstein dairy cows. ***Journal of Animal Science*** 83, 1377-1384.
4. BOHMANOVA J., MISZTAL I., COLE J.B., 2007 – Temperature-Humidity Indices as Indicators of Milk Production Losses due to Heat Stress. ***Journal of Dairy Science*** 90, 1947-1956.
5. BOURAOUI R., LAHMAR M., MAJDOUB A., DJEMALI M., BELYEA R., 2002 – The relationship of temperature-humidity index with milk production of dairy cows in a Mediterranean climate. ***Animal Research*** 51, 479-491.
6. BROUČEK J., NOVÁK P., VOKŘÁLOVÁ J., ŠOCH M., KIŠAC P., UHRINČAŤ M., 2009 – Effect of high temperature on milk production of cows from free-stall housing with natural ventilation. ***Slovak Journal of Animal Science*** 42(4), 167-173.
7. DIKMEN S., HANSEN P.J., 2008 – Is the temperature-humidity index the best indicator of heat stress in lactating dairy cows in a subtropical environment? ***Journal of Dairy Science*** 92, 109-116.
8. JAŚKOWSKI J.M., URBANIAK K., OLECHNOWICZ J., 2005 – Stres cieplny u krów-zaburzenia płodności i ich profilaktyka (in Polish). ***Życie weterynaryjne*** 80(1), 18-21.
9. JÓŹWIK A., KRZYŻEWSKI J., STRZAŁKOWSKA N., POŁAWSKA E., BAGNICKA E., WIERZBICKAA., NIEMCZUK K., LIPIŃSKA P., HORBAŃCZUK J.O., 2012 – Relations between the oxidative status, *mastitis*, milk quality and disorders in animal reproductive functions – a review. ***Animal Science Papers and Reports*** 30(4), 297-307.
10. MADER T. L., DAVIS M. S., BROWN-BRANDL T., 2006 – Environmental factors influencing heat stress in feedlot cattle. ***Journal of Dairy Science*** 84, 712-719.
11. NATIONAL RESEARCH COUNCIL. 1971. A guide to environmental research on animals. ***National Academy of Science, Washington, DC.***
12. RAVAGNOLO O., MISZTAL I., 2000 – Genetic Component of Heat Stress in Dairy Cattle, Parameter Estimation. ***Journal of Dairy Science*** 83, 2126-2130.
13. ROMANIUK W., OVERBY T. AND OTHERS., 2005 – Systems of maintenance of cattle. Reference book. Praca zbiorowa. Projekt Bliźniaczy PHARE, Standardy dla Gospodarstw Rolnych. Warszawa: Instytut Budownictwa, Mechanizacji i Elektryfikacji Rolnictwa; Duńskie Służby Doradztwa Rolniczego **(?).**
14. ST. PIERRE N. R., COBANOV B., SCHNITKEY G., 2003 – Economic Losses from Heat Stress by US Livestock Industries. ***Journal of Dairy Science*** 86(E. Suppl.), E52-E77.
15. SPIERS D.E., SPAIN J.N., SAMPSON J.D., RHOADS R.P., 2004 – Use of physiological parameters to predict milk yield and feed intake in heat-stressed dairy cows**.** ***Journal of Thermal Biology*** 29, 759-764.
16. WEST J.W., 2003 – Effects of Heat-Stress on Production in Dairy Cattle. ***Journal of Dairy Science*** 86, 2131-2144.
17. WEST J.W., MULLINIX B.G., BERNARD J.K., 2003 – Effects of Hot, Humid Weather on Milk Temperature, Dry Matter Intake and Milk Yield of Lactating Dairy Cows. ***Journal of Dairy Science*** 86,232-242.
18. VITALI A., SEGNALINI M., BEROCCHI L., BERNABUCCI U. NARDONE A. LACETERA N., 2009 – Seasonal pattern of mortality and relationships between mortality and temperature-humidity index in dairy cows. ***Journal of Dairy Science*** 92, 3781-3790.