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ELIGIBILITY OF LYING BOXES AT DIFFERENT THI LEVELS IN A FREESTALL BARN*

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Abstract

Cattle show a high sensitivity to changeability of microclimate conditions and heat stress that causes changes in the welfare and behaviour of cows. The presented study aimed at determining the relationship between the temperature humidity index (THI) value during the summer period and daily behaviour of dairy cows, including eligibility of lying boxes. All these aspects were measured under real production conditions. The investigated area, where microclimate conditions measurements were conducted, was a free-stall barn with single and double boxes, with manure and feeding alleys, housing 40 Holstein-Friesian cows. Observations were made on the behaviour of the cows based on a preference test concerning their choice of the best areas with respect to three ranges of THI values: neutral (N), warm (W) and hot (H). During the warm and hot period the research demonstrated a positive correlation between the level of THI and the share of standing cows (in period W – $P<0.03$ and H – $P<0.008$), and an inversely proportional one between the level of THI with participation of lying down cows (periods: W – $P<0.06$; H – $P<0.004$) and the length of their laying bouts in double boxes. The double boxes area was predominantly occupied, whereas single boxes area was the least often used. The occupation of manure alley areas was positively correlated with the level of THI.

Key words: temperature-humidity index, dairy cow, behaviour, lying bout length

The high productivity of dairy cows contributes to the production of large amounts of heat by their organisms, whose excess must be discharged into the environment. In order to cool their bodies, cows breathe faster and consume less feed during hot weather, which in turn causes a decline in milk production (Armstrong, 1994; West, 2003). However, high temperatures and high relative humidity make this process difficult and the cow's body temperature increases (Allen et al., 2015), which may result in impaired thermoregulation and heat stress (Rhoads et al., 2009).

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Cattle farmers all over the world are facing the problem of heat stress in dairy cattle. Air velocity and intensity of solar radiation, particularly in unshaded areas of a barn, in addition to the temperature and relative humidity, affect heat stress formation (Kadzere et al., 2002; West et al., 2003; Horky et al., 2015). THI (temperature humidity index) with its subsequent modifications (Mader et al., 2006), comprising the air velocity and intensity of solar radiation (Herbut and Angrecka, 2013), was used to describe the comfort and heat stress in cows.

Dairy cattle kept in a free-stall system spend their entire lives in a barn, so a cattle breeder should provide everything that is optimal for their welfare. It is particularly important to maintain the suitable temperature and humidity conditions, the conditions affecting the cows' rest, their behaviour, hormonal and metabolic changes, and the milk production (Tucker et al., 2009; Herbut and Angrecka, 2013; Adamczyk et al., 2015).

As the cows spend from 8 to 16 h per day in a lying position (Tucker et al., 2003), the optimization of their undisturbed lying bout is very important for their health. The appropriate lying bout helps to avoid hoof diseases and lameness and also helps to increase their feed consumption and rumination activity (Manninen et al., 2002; De Palo et al., 2006; Grant, 2006; Kominkova et al., 2015). The comfort of lying cows, including getting up and lying down, depends on inter alia: the size and the type of boxes, the type of partitions between the boxes, the number of stalls in relation to the number of animals (Fregonesi et al., 2007), social relations in the herd (Galindo and Broom, 2000), the use of resting space and their nutrition (Camiloti et al., 2012). The temperature of the litter, which is dependent on the air temperature (Angrecka and Herbut, 2016), its quality and depth is also of equal importance (Kaczor et al., 2011).

The aim of the study was to determine the relationship between THI value and the everyday cow behaviour (eligibility of boxes and manure alleys) during summer period.

Material and methods

Structures and management

The study was conducted for 3 summer months (June–August) of 2013 in a free-stall barn in southern Poland (N 50° 8' 59" E: 19° 45' 12") in typical mild climate. Ventilation of the barn was provided by a ridge vent (air exhaust) and longitudinal curtain walls (air supply). The longitudinal wall of the barn (from the south) was completely open during the research period.

The separated area of 13.75 × 30.0 m housed 55 lying boxes including: 18 single (SB), 37 double (DB), two manure alleys (MA1, MA2) and the feeding alley (FA), in which the cows were kept during feeding time (Figure 1).

These were 12 × 245 cm double boxes and 120 × 260 cm single boxes with the rim shoulder at the height of 126 cm. All the boxes were bedded with 15 cm long cut straw (5 kg of straw per cow daily). The average straw thickness in the box area was 12 cm. Manure and feeding alley floors were made of grooved concrete. Manure was removed mechanically from the manure alleys once a day during morning milking.

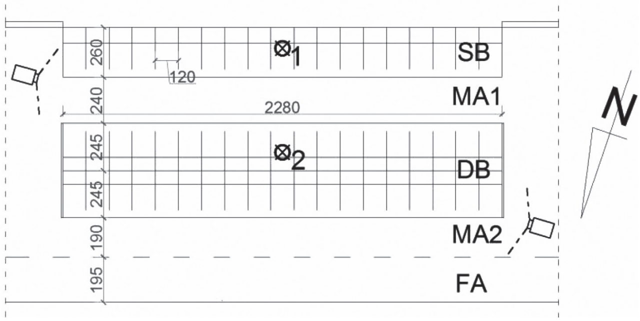

Figure 1. Projection of the tested area with marked locations of measurement and observation cameras; 1, 2 – measurement points of temperature, relative humidity and air velocity, SB – single boxes, DB – double boxes, MA1, 2 – manure alleys, FA – feeding and manure alley

Animals and feeding

A group of 40 Holstein-Friesian cows, giving daily 21.6 kg of milk, kept using commercial technology, was located in the part of the barn selected for the analyses. All the cows, during the study period, were between 50th and 150th day of lactation and had similar body dimensions. The experiment was designed in such a way that the cows, in order to ensure them free choice, had more boxes than the size of the group. During the research the cows were given zootechnical and veterinary care.

The lactating cows were fed corn silage (21.0 kg), alfalfa and grass hay (3.5 kg), dehydrated alfalfa (2.5 kg), concentrate (13.0 kg) and mineral and energy components; the feeds were administered as TMR at 09:00. Feeding was allowed throughout the 24-hour period, except during milking. The cows were milked twice a day: at 07:00 and at 17:00.

Behavioural and environmental measures

In order to determine the lying and standing bouts of the tested cows group, a system of cameras equipped with infrared motion detection that allowed the filming and taking of pictures was installed (Figure 1). The following data were obtained from an examination of the recordings:

– total lying time per day (LTD),
– average lying time per hour (LTH),
– percentage of the lying down cows (LC).

The percentage occupancy of the lying boxes was determined as the number of cows lying in different areas of the experimental zone (SB, DB, MA1, MA2) in relation to the total number of cows. Cows lying down means that at least the hind part of the animal's body was lowered down.

The temperature and relative humidity were measured by LB-710 sensors (Label Reguły, Poland) with a measuring range for temperatures from –40 to +85°C and relative humidity from 0 to 99.9%. The air flow velocity was measured by HD 103T (Delta Ohm, Padua, Italy) sensors with a measuring range of 0–5 m/s. The sensors were placed in the zone occupied by cows 1.0 m above the floor in selected lying boxes. Sensor 1 (in parietal boxes) was within sunlight. Sensor 2 (in double boxes) was beyond the reach of solar radiation (Figure 1). The solar radiation values were measured by LP Pyra 03 pyrometer (Delta Ohm, Padua, Italy). All measurement results were recorded automatically every 6 minutes.

Based on the obtained results of the microclimate parameters measurements, the calculations of the THI value were conducted according to the formula (Mader et al., 2006):

$$THI = 4.51 + THI_{NRC} - (1.992 \cdot V) + (0.0068 \cdot RAD)$$

where:

THI_{NRC} – temperature humidity index calculated based on National Research Council formula (1971),

V – air velocity, m/s,

RAD – intensity of solar radiation, W/m^2.

The accuracy in time was stated in min. Every behavioural event was associated with an average hourly value of THI 1, THI 2 or THIavd (average daily THI between THI 1/2) value in the period in which the event occurred.

Statistical analysis

The LTD, LTH, LC (in each part of research area) with corresponding THI was processed using analysis of the Spearman's correlation coefficient (r) (Version 12.0, 2013). The Student's t-test was used to estimate the statistical significance of the obtained values. Data were considered significant at $P<0.05$.

Results

Barn environmental conditions

During the three months of research in the free-stall barn the temperature, relative humidity and air movement velocity were noted and are presented in Table 1. The maximal daily solar radiation was in the range from 776 to 1001 W/m^2.

Based on the calculated value of temperature and humidity indicator, the results obtained were divided into periods characterized by different levels of thermal comfort throughout the whole day: neutral (occasionally exceeded THI values = 74), warm (time of THI>74 occurrence lasted less than 12 h) and hot (time of THI>74 occurrence lasted longer than 12 h).

During the 3-month study period THI values equal to 84 or higher occurred only during period H and lasted up to 4 h, and therefore the highest THI range was defined as >80.

Out of all the 88320 obtained measurements of temperature and relative humidity, air movement velocity and solar radiation, a period of 9 days (July 14 to 22, 2013) was chosen as repeatable and representative for a concise presentation of the results. It consisted of three consecutive 3-day periods: neutral (N), warm (W) and hot (H) (Figure 2).

Table 1. The temperature, relative humidity and air movement velocity over the studied period

		June	July	August
t (°C)	average	18.8	21.0	21.0
	minimum	10.3	9.6	11.2
	maximum	33.7	35.5	36.4
RH (%)	average	78.9	69.0	65.5
	minimum	41.3	33.3	26.6
	maximum	97.2	93.5	93.1
V (m/s)	average	0.57	0.51	0.60
	minimum	0.10	0.07	0.06
	maximum	2.11	1.75	2.46

t – air temperature.
RH – relative air humidity.
V – air velocity.

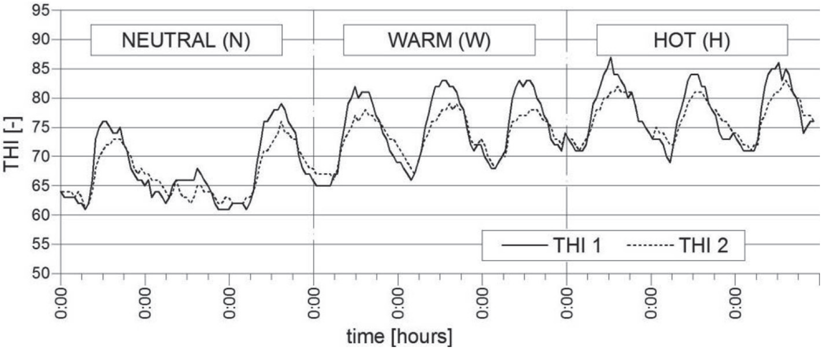

Figure 2. A sample of research period

In the presented period, the THI 1 values were higher than the THI 2 values during daylight hours i.e. between 08:00 and 20:00. The greatest differences occurred around noon (12:00) and amounted up to 6 units. During the night hours THI 2 had higher values, however the differences did not exceed 3 units (Figure 2).

Lying boxes occupancy

In the N period, both during the day and the night, LC mostly occupied the DB. At night, these stations were chosen by 35% of the cows, and during the day by 27%. The SB during the night hours was chosen by only 8.5% of the cows, unlike LC amounting to 7.6% during the day. It was observed that even in the SB area when the THI 1 was temporarily higher than 74, the cows did not give up resting on them. A small LC was also visible on MA1 and MA2, both during the day and at night. In the N period 2.2% of the cows lay down in MA1 or MA2 with maximal average hours of LC amounting to 6.3% (Figure 3), but no regularity in this behaviour was observed.

During the W period the cows most commonly lay down in the DB area – LC at night amounted to 31.4%, and to 26.7% during the day. SB was occupied during the night hours by 9.3% of the cows, contrary to LC amounting to 9.1% during the day. In the DB area, when THI > 74, LC amounted to 25.3% and to 8.3% in the SB. The sum of LC in the MA1 and MA2 alleys amounted to 2.6% (Figure 4).

The DB were also commonly used by the cows during the H period (Figure 5). At night LC amounted to 22.5%, and during the day to 18.3%. LC in the SB during night hours only amounted to 8.6%, in comparison with 7.7% during the day.

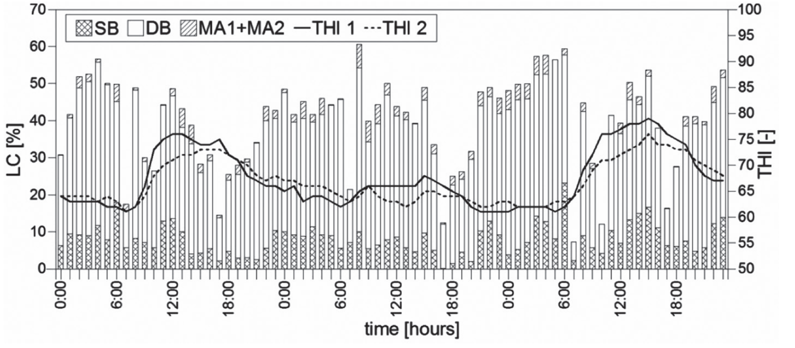

Figure 3. LC in different experimental areas of period N

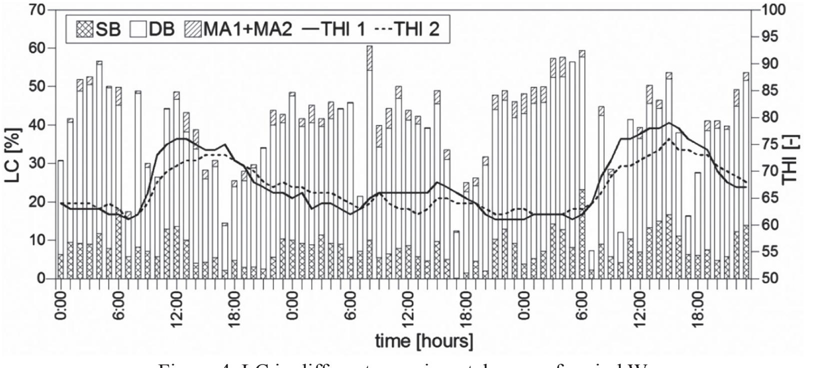

Figure 4. LC in different experimental areas of period W

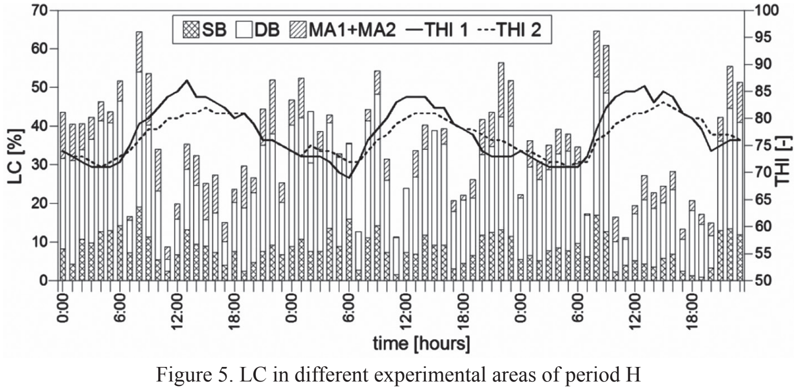

Figure 5. LC in different experimental areas of period H

It was observed that when the THI ranged from 75 to 79 there was 23.7% of the cows in the DB area, and 9.8% in the SB. However, when THI>79 in the DB, 14.3% of the cows lay down there, while only 6.4% in the SB. LC in MA1 and MA2 was recorded during the whole day – 5.7% on average, the highest between 21:00 and 02:00 (8.0%), and between 08:00 and 10:00 (8.8%).

An inversely proportional correlation of THI to LC in the DB was observed in the periods: N ($r = -0.40$; $P<0.01$), W ($r = -0.41$; $P<0.05$) and H ($r = -0.62$; $P<0.01$). There was a similarly important connection between SB and THI; THI 1 ($r = -0.58$; $P<0.05$) was observed during the H period.

The increase in THI in SB areas along with the LC rise was observed over three months of research during the N periods (Table 2). THI in the range of 74 to 80 was the most frequently noted between 11:00 and 17:00, when the cows, after feeding, looked for a place to rest. LC in the DB dropped by 2.8%, although in that part of the research area the most stable environmental conditions prevailed – the THI 2 values did not rise above 80. The values of THI>74 occurred only in late afternoon hours, usually just before milking. Characteristic for the N period was a small LC in MA1 and MA2 and, as seen from the observation, the occupancy was very occasional (Table 2).

Table. 2. LC in different experimental areas in periods N, W, H in dependence to THI

Period	Neutral								
part of research area	SB*			DB**			MA1+MA2***		
range of THI	<74	74–80	>80	<74	74–80	>80	<74	74–80	>80
LC (%)	7.5	8.8	–	29.5	26.7	–	2.2	1.9	–
Period	Warm								
part of research area	SB*			DB**			MA1+MA2***		
range of THI	<74	74–80	>80	<74	74–80	>80	<74	74–80	>80
LC (%)	10.2	6.2	9.8	32.0	25.3	–	3.8	1.7	1.4
Period	Hot								
part of research area	SB*			DB**			MA1+MA2***		
range of THI	<74	74–80	>80	<74	74–80	>80	<74	74–80	>80
LC (%)	9.4	8.8	6.4	22.3	23.7	14.3	4.7	6.6	5.8

* Took into account the THI 1 value.
** Took into account the THI 2 value.
*** Took into account the values calculated as an hourly average value of THI 1 and THI 2.

Smaller LC in the SB during the W periods with THI 1 in the range of 74 to 80 was not directly related to the microclimatic conditions in the barn, because such THI values occurred at milking times and during the time when the cows occupied the FA alley. Larger LC with THI 1 > 80 occurred between 11:00 and 16:00, when the cows returned to their stalls after feeding.

The DB area again was the most stable in terms of microclimate conditions. THI 2 was lower than 74 between 22:00 and 08:00, which was reflected in LC value. The decline occurred with the increase in THI 2. An increase was observed in LC that chose MA1 and MA2 as the lying alleys, especially during night hours when the THI decreased and cooling of the animals from the floor was possible (Table 2).

Less favourable climate conditions were during the H periods, which in turn had a significant impact on the cows' behaviour. In the SB area THI 1 < 74 occurred only in the middle of the night, and THI 1 > 80 even within 11 hours. After the morning milking the cows returned to the barn where, due to the high air temperature and insolation, the temperature and humidity conditions deteriorated. It happened especially in the SB area, which did not encourage the cows to lie down. A similar situation occurred with their lying down in the DB area. THI 2 stabilized in the range between 74 and 80, with smaller values occurring only sporadically. Even between 20:00 and 03:00 the THI > 74 dominated. During that time the cows were looking for a place to rest so, regardless of the conditions, they lay down in the stalls. Between 11:00 and 16:00, when the climate conditions in the barn were at their worst, the cows did not lie, but either stood in the alleys or the stalls. By doing so, the cows searched for the possibility of cooling down by air movement. During the H periods it was possible to see that the cows deliberately lay down on MA1 and MA2, which enabled them to give off heat through the moist, non-insulated floor. However, with THI > 80 the cows were more frequently standing than lying in the alleys (Table 2).

Lying down bouts

Based on images from the monitoring system, LTD was calculated in different parts of the research area (Figure 6).

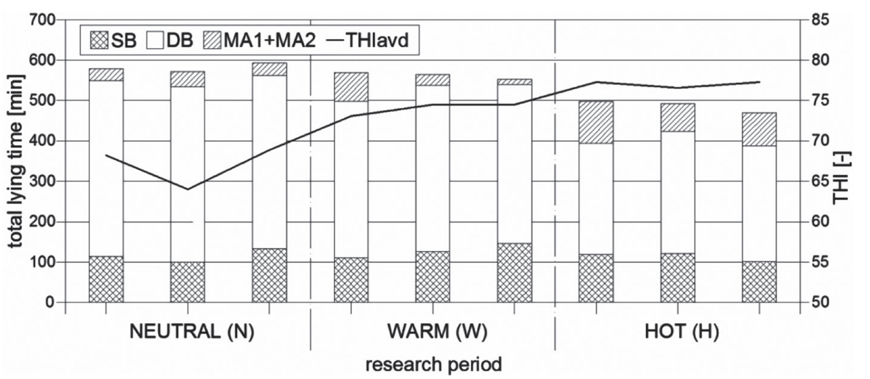

Figure 6. LTD of the cows depending on the area and the THIavd

In the DB area LTD change occurred (Figure 6). During the N period the cows spent there on average 433 min/d, during the W period 397 min/d, and during the H period 288 min/d. It follows that a gradual reduction of LTD ($r = -0.73$; $P<0.04$) proceeded along with an increase in THI values.

LTD in MA1 and MA2 increased along with an increase in THI value (Figure 6). While in the N and W periods it was 32–37 min/d, in the H period it increased to 85 min/d. Although the correlation of THI and LTD did not show significance (r = –0.61; P>0.05), the observations suggest that the deterioration of environmental conditions in the barn is reflected in increased LTD in MA1 and MA2.

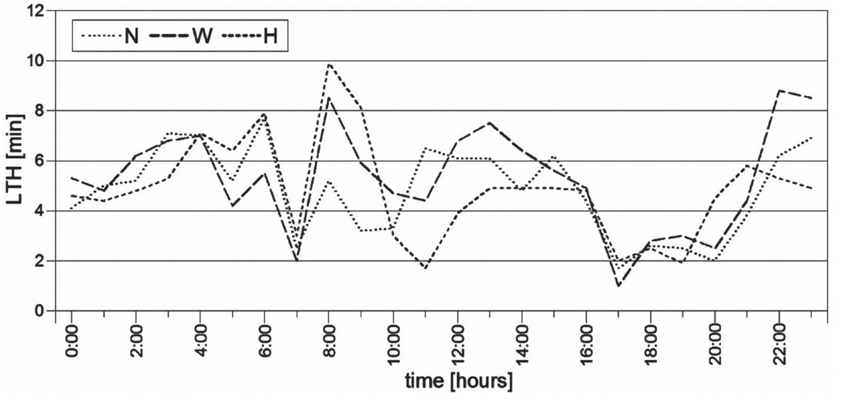

Figure 7. LTH in SB in periods N, W, H

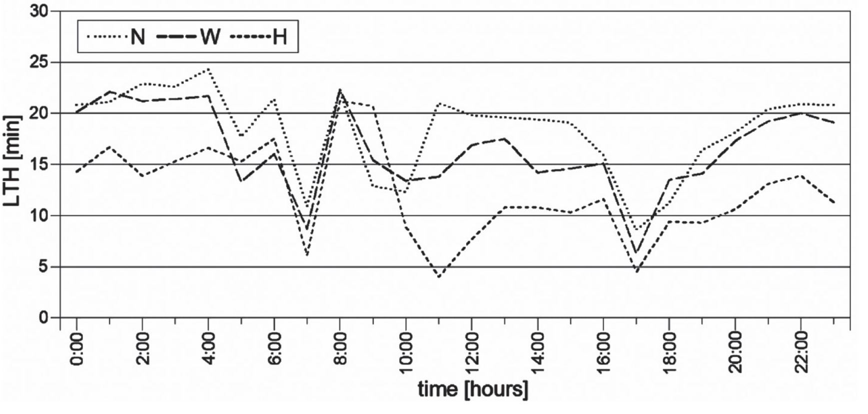

Figure 8. LTH in DB in periods N, W, H

The captured images were also used to calculate the LTH of the cows from the experimental group. Comparison of LTH during an hour divided into different experimental areas allowed for registering the differences in the N, W and H periods.

LTH in the SB was characterized by a lack of stable progress in each period. The longest time when the cows occupied SB was during the night – 6 min/h for each period. After the morning milking the largest amount of LTH was spent by the cows in the H period (on average 10 min/h), whereas after the afternoon milking LTH, regardless of the period, dropped to nearly 2 min/h. Between the milkings the SB were occupied for the shortest time during the H period (Figure 7).

The time spent lying on the DB was longest at night in the N and W periods (21 and 19 min/h, respectively) with 14 min/h in the H period. At 08:00 the LTH was similar for all the periods, however in the H period it extended to 2 h. Between

11:00 and 16:00 a diversity of LTH was visible, reaching the following values: N – 19 min/h, W – 15 min/h and H – 9 min/h (Figure 8).

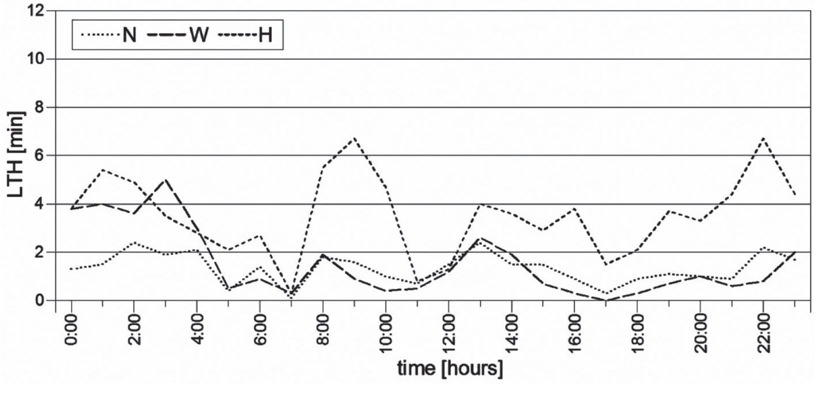

Figure 9. LTH in MA1, 2 in periods N, W, H

LTH in MA1and MA2 was maximally 3 min/h in the N period and 4 min/h in W period. The longest LTH in MA1, from 2 to 7 min/h, occurred during the H period, especially between 21:00 and 02:00 and from 08:00 to 10:00 (Figure 9).

Discussion

Application of the Mader et al. (2006) formula allowing for obtaining the THI, taking into account air velocity and the intensity of solar radiation, makes it possible to better define the microclimate conditions in the barn (Herbut and Angrecka, 2013). Charts presenting the course of THI 1 and THI 2 show the differences in microclimatic conditions occurring in a relatively small area occupied by the cows housed in the barn, which confirms the observations of Herbut et al. (2015 a). These differences resulted from higher temperatures during the day at the measurement station 1, located in the sunlight zone and in proximity to the open longitudinal wall of the barn with lowered curtains (Herbut, 2013). As a result of these fluctuations in temperature and relative humidity, and as a consequence of the THI value, these differences were much higher than at the measurement station 2.

Hahn et al. (2009) classified the levels of heat stress in the following ranges of THI: <74 – normal state, 75 to 78 – state of alarm, 79 to 83 – state dangerous to the health of the cows, >84 – there is a life-threatening situation. In the present study, the period of the THI values ranging from 75 to 83 occurred the most frequently, whereas higher values rarely occurred. This shows a serious threat to the welfare and the occurrence of heat stress in cows which, according to Adamczyk et al. (2013), is dangerous for efficient livestock production, including milk production.

A momentary, even slight deterioration in microclimate conditions did not cause any discomfort and changes in the cows' behaviour, which was best visible during the N period. The changes in behaviour manifesting themselves as an increased LC in MA1 and MA2 and a reduction of LC in the SB and DB started in the W periods. Their appearance of the H periods was associated with significant changes in the daily routine of the cows. In addition to limited LC in the SB and DB – both at night and during the day – the LTH of the cows grew immediately after the morning milking. In the N and W periods, after returning from milking, the cows were lying down for an hour, and they slowly headed toward the FA after consuming fresh feed.

Along with an increase in THI there was an increase in LC in MA1 and MA2, which resulted from the cows trying to cool themselves down from the concrete and wet-from-urine floors. The strongest need for cooling down occurred in the cows in the H period. However, it was observed that the cows preferred to lay down in the alleys during the night (when the floor was not hot) rather than during the day. This behaviour can be explained by an attempt to minimize the cow's body contact with the floor, where the heat from the sun insolation is cumulated (Tapki and Sahin, 2006). The N period, when the environmental conditions were most favourable for the cows, was characterized by the random eligibility of the lying boxes. Thus, the increase in THI affected the shortening of the cows' lying bouts in the SB and DB and the lengthening of the lying time in the MA, especially during the day.

In the conducted studies, regardless of the THI value, most of the cows occupied the DB area. In relation to the SB area it was beyond the reach of insolation, thus favouring the cows' presence there. Moreover, the smallest amplitude of THI fluctuations was observed in this part of the barn, which was higher than 80 only during the H period. That is why the cows, experiencing the favourable microclimate conditions, chose the DB area. Presumably the herd instinct played a crucial role here – visible as the occupation of, as well as indicating the best stations by the 'most sensitive' cows.

In practical, architectural design, the double boxes area in a new barn should be positioned at a distance from the curtain walls. It seems necessary to conduct investigations on the role of the flooring type in the cooling down and heating of cows with regard to heat transfer in different weather conditions.

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