Relationship between THI level and dairy cows’ behaviour during summer period

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ABSTRACT
The presented study determining the relationship between the Temperature Humidity Index (THI) value during the summer months (June–August) and daily behaviour of 40 Holstein–Friesian dairy cows, including the length of standing, laying bouts and locomotor activity. Behaviour observations were conducted on a preferences test concerning their choice to time and place of rest with respect to time duration of THI: neutral (maximum 3 h with THI = 68), warm (time of THI > 68 occurrence lasted less than 12 h) and hot (time of THI > 68 occurrence lasted longer than 12 h). Obtained results was processed using analysis of the Spearman’s correlation coefficient with significant at \( p < .05 \). The results showed a decrease in daily total lying time between the neutral and hot periods from 9.9 to 7.8 h/d. Along with the increase in THI by 1 unit between the warm and hot periods, there was observed a decrease in total lying time by 38 min/d in the cubicles. With an increase in the THI was also observed an increase by 15 min/d in the lying cows in the manure alleys during the night-time. During the warm and hot periods, the cows’ activity showed a negative correlation with the increasing THI. Cows changed their behaviour during the summer depending on the prevailing environmental conditions. The behavioural studies on cows, without taking into account the variability of microclimate conditions, can lead to their inaccuracy and the misrepresentation of their results.

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Introduction
The high productivity of dairy cows contributes to the production of large amounts of metabolic heat, which must be discharged into the environment. In order to cool their bodies, cows increase their respiration rates and consume less feed during hot weather, which in turn causes a decline in milk production (West 2003; Tousova et al. 2017). However, high temperatures and high relative humidity make this process difficult and the cow’s body temperature increases (Allen et al. 2015). This may result in impaired thermoregulation and heat stress (Rhoads et al. 1992).

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 2003; Angrecka & Herbut 2016). In order to describe the comfort and heat stress in cows, scientists have been using a lot of indices such as, Equivalent Temperature Index (Baeta et al. 1987) or Comprehensive Climate Index (Sejian et al. 2015), are utilised. However, since the 1950s (Thom 1959) most often is used the Temperature Humidity Index (THI).

Dairy cattle kept in a free-stall system spend their entire lives in a barn, so a caretaker should provide everything that is optimal for their welfare (Godyń et al. 2013; Hempel et al. 2016). Suitable temperature, humidity conditions, ventilation and ammonia concentration are particularly important because they affect the cows’ rest conditions, their behaviour, hormonal and metabolic changes and milk production (Herbut & Angrecka 2014; Horky 2014; Herbut et al. 2015). One of the behavioural characteristics being an indicator of the cows’ physiological and health state is their locomotor activity and the length of lying and standing bouts (Tolkamp et al. 2010; Radoń et al. 2014; Angrecka & Herbut 2017). Any deterioration of environmental conditions creates significant changes in the above-mentioned characteristics (De Palo et al. 2006; Adamczyk et al. 2015).

As the cows spend from 8 to 16 h per day in a lying position (Tucker et al. 2003; Endres & Barberg 2007; Brzozowska et al. 2014), the optimisation of their
undisturbed lying bouts is very important for their health. It helps to avoid hoof diseases, lameness and also helps to increase their feed consumption and rumination activity (Grant 2006; Kominkova et al. 2015; Horky et al. 2017). The comfort of lying cows, including getting up and lying down, depends on inter alia: the size and the type of cubicles, the type of partitions between the cubicles, the number of free-stalls in relation to the number of animals (Fregonesi et al. 2007), social relations in the herd (Galindo & Broom 2000), the use of resting space and their nutrition (Mattachini et al. 2011). On commercial farms the lying time can be used as a measure of a cow’s welfare (Vasseur et al. 2012). This is particularly important in the case of heat stress, which reduces the lying time (Anderson et al. 2013). It was also confirmed in research performed by Cook et al. (2007) in which with increasing of THI the lying time was reduced by 3 h. Along with the deteriorating microclimatic conditions also decreases the locomotor activity (West 2003). However, in research of Brzozowska et al. (2014) in the course of the year the cows did the largest number of steps in the period June–September.

The presented study aimed to determine the relationship between the THI value and daily dairy cows’ behaviour – the length of standing and laying bouts and locomotor activity during the summer. All these aspects were measured in one of the commercial farm.

Materials and methods

Structures and management

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

The separated area of 13.75 × 30.0 m housed 55 cubicles, two manure alleys and a feeding alley, in which the cows were kept during feeding (Figure 1). All the cubicles were bedded with 15 cm long cut straw (4–5 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.

Animals and feeding

Forty Holstein–Friesian cows with a mean daily milk production of 21.6 kg (SE 1.7), was kept in a selected part of the barn (stocking density 10.31 m²/cow). All the cows during the research period were between the 50th and 150th d of lactation and had similar body dimensions. The experiment was designed in such a way that the cows, in order to ensure a free choice, had more cubicles than the size of the group. During the research the cows were covered by 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 am. Feeding was allowed throughout the 24-h period, except during milking. The cows were milked twice a day: at 07:00 am and 05:00 pm.

Behavioural and environmental measures

In order to determine the lying and standing bouts of the tested cows group, a system of cameras equipped with cameras equipped with cameras equipped with cameras equipped...
with infrared motion detection that allowed the filming and taking of pictures was installed. The following data were collected over 90 consecutive days of video data:

- total lying time per day (LTD),
- average lying time per hour (LTH),
- locomotor activity – number of steps taken by the cow in the hours between milking (STEPS),
- percentage of the standing cows (SC),
- percentage of the lying down cows (LC).

The percentage occupancy of the lying cubicles was determined as the number of cows lying in different areas of the experimental zone 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.

During the experimental period the STEPS measurements were conducted using pedometers of the Afifarm 3.08 system (Afimilk, Israel). The locomotor activity was divided into the daytime (between morning and afternoon milking on the same day – 07:00 am to 04:00 pm) and night-time (between afternoon and morning milking on the next day – 05:00 pm to 06:00 am).

The temperature and relative humidity were measured by LB-710 sensor (Label, Reguly, Poland) with a measuring range for temperatures from -40 to +85 °C and relative humidity from 0 to 99.9%. The sensors were placed in the zone occupied by cows 1 m above the floor in selected cubicles. All the measurement results were recorded automatically every 6 min.

Based on the obtained results of the microclimate parameters measurements, the calculations of the THI value were conducted according to the formula (NRC 1971):

\[
\text{THI} = \frac{1}{2}(1.8 \times T_{db} + 32) - (0.55 - 0.0055 \times RH) \\
\times (1.8 \times T_{db} - 26),
\]

where: \(T_{db}\) – dry bulb air temperature, °C, RH – relative air humidity, %.

Based on the calculated value of the temperature and humidity index, the results obtained were divided into periods characterised by different time duration of thermal comfort (THI) throughout the whole day: neutral (N) (maximum 3h with THI = 68), warm (W) (time of THI > 68 occurrence lasted less than 12 h) and hot (H) (time of THI > 68 occurrence lasted longer than 12 h).

Every behavioural event was associated with an: THIavh (average hourly THI), THIavd (average daily THI), THIavp (average THI from the part of the day) value in the period in which the event occurred.

**Statistical analysis**

The observational unit was total lying time per day (LTD), average lying time per hour (LTH), average number of steps taken by the cow in the hours between milking (STEPS), percentage of the standing cows (SC), percentage of the lying down cows (LC). The experimental unit was group of forty cows.

The LTD, LTH, LC, SC (in each part of the research area) and STEPS with corresponding THI was processed using analysis of the Spearman’s correlation coefficient (r) in Statistica programme (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 \(p < .05\).

**Results**

**Barn environmental conditions**

Out of all the 88,320 obtained measurements, a period of 9 d was chosen as repeatable and representative for a concise presentation of the results (Figure 2). In the time of 3 months the average THI values for each

![Figure 2. A sample research period.](image-url)
period were: in N equal 62 (SE 2.4), in W 69 (SE 1.5) and in H period 74 (SE 2.7).

**The lying down and standing behaviour**

During the N period in the night-time hours 45.8% (SE 1.7) of the cows were lying, while in the daytime hours this was between 37.2% (SE 0.1). Most cows (59.3%) were lying at 08:00 am, i.e. in the first hour after milking, and the fewest at ca. 10:00 am, after fresh feed supply. The increase in LC was usually visible at 03:00 pm, when 51.7% of the group was lying. During the night-time in the W period 45.9% (SE 1.2) of the cows were lying, while in the daytime hours this was 37.3% (SE 0.2). The increase in LC was visible between 01:00 pm and 02:00 pm – 47% (SE 1.5). The H period, in comparison to the aforementioned periods, had smaller LC: at night-time – 38.2% (SE 1.7), in the daytime 29.8% (SE 0.7). Most cows were lying between 08:00 am and 09:00 am, i.e. immediately after milking (57%) and the fewest at 11:00 am. Also, during the afternoon hours no increase in LC was observed – 32.9% (Figure 3). Statistical results for these parameters are presented in Table 1.

Standing cows mostly stood by the feed bunk consuming the feed between the hours of 10:00 am to 12:00 pm, i.e. up to 3 h after it was given – 69.9%; 01:00 pm to 04:00 pm – 46.5%; and at night-time – 51.1%.

Between SC in the feeding alleys and the THIavh value there was observed a direct proportional correlation for the W period \( r = 0.75; p < .02 \) and for the H period \( r = 0.55; p < .02 \). The analysis of LC divided into night-time and daytime showed a strong correlation with the change in THI value. Both at night \( r = -0.69; p < .04 \) and during the day \( r = -0.68; p < .01 \), the increase in THI was observed with a LC decline in the analysed experimental areas.

**Cows’ locomotor activity**

The average activity hours (STEPS) between milkings obtained from the herd management system were related to the THIavp value. At night-time (\( p > .05 \)) STEPS remained at a similar level, regardless of the THI value. A greater decrease was observed only when the average THI values were close to the limit. During the daytime in the N period, STEPS was higher than in the W and H periods, but over the entire study period it showed a negative correlation with the changing THIavp \( r = -0.81; p < .04 \). It was observed that during the daytime, along with an increase in SC, a decrease in STEPS occurred \( r = -0.65; p < .03 \).

**Lying down bouts**

Cows LTD, as shown in Figure 4, depended on the THI value. It was found that LTD in the N (581 min) and W (562 min) periods was similar. In the H period a significant drop in LTD was noted and amounted to ca. 500 min.

The pictures taken were used to calculate the LTH of the cow from the experimental group. Cows spent the longest time lying at night between 08:00 pm and 06:00 am, where LTH during the N and W periods was similar and was 28 and 27 min/h, respectively. In the H period it decreased to 23 min/h (Figure 5).

During the N and W periods, after returning from the morning milking, LTH was 29 and 32 min/h, respectively. Then it started to drop from 09:00 am,
when fresh feed was given, until 10:00 am for the N period (17 min/h on average) or until 11:00 am for the W period (20 min/h on average).

During the H period, after returning from the morning milking, the cows rested for 2 h (08:00 am–09:00 am) and LTH amounted to 36 min/h. Between 10:00 am and 12:00 pm, LTH ranged from 5 to 20 min/h (average 12 min/h). Between 01:00 pm and 04:00 pm LTH stabilised at 19 min/h. For the results of the LTH the SE was in range 0.7–1.3.

It was observed that along with the deterioration of microclimatic conditions, during the N, W and H periods there were significant differences in the length of lying bouts that occurred in the cubicles and manure alleys (Table 2).

**Discussion**

According to Metz (1985) depriving cows of the possibility to have a rest in a lying position for 3 h, and according to Kanjanapruthipong et al. (2015) for 2 h, causes a deterioration in an animal’s welfare by disturbing their daily routine. In the H periods, after morning milking occurred depriving the possibility of lying for around 1 h, which resulted in a disturbance of cows comfort. This in turn resulted in a temporary abstinence from feed intake and was changed for the immediate and extended resting time (Haley et al. 2000). However, during the H period the lying time was increased up to at least 2 h. There were situations, particularly on hot days, that more than 70% of the herd needed a longer rest and even giving fresh feed did not cause their moving to the feeding alley. However, it was observed that the cows reacted with

| Part of research area | THIavd | Period | Cubicles | Manure alleys |
|-----------------------|--------|--------|-----------|---------------|
| N                     | 549    | 32     | 62.6      |
| W                     | 525    | 37     | 69.2      |
| H                     | 402    | 85     | 73.2      |

*Time in min/d.

**Figure 4.** LTD (daily lying time) of the cow depending on the area and the THIavd (average daily THI).

**Figure 5.** LTH (hourly lying time) of the cow in periods N, W, H.
curiosity and moved to the feeding alley on the sound of moving feed closer to the feeding bunk – around 11:00 am. At this time the LC definitely decreased and the SC increased, regardless of the microclimate conditions.

The N period, when the environmental conditions were favourable for cows, was characterised by the random eligibility of cubicles. During H period, the LC dropped because the cows did not want to lie in heated cubicles or on manure alley surfaces. Lying on a hard, concrete floor can be especially painful for cows because it causes, among others, pressure on the milk-filled udders (Osterman & Redbo 2001). Along with an increase in the THI was observed an increase in the LC in the manure alleys because the cows were trying to cool down from the concrete and urine damp floors. The strongest need for cooling down occurred in the cows in the H periods. However, it was observed that the cows preferred to lie in alleys during the night-time (when the floor was not heated) rather than during the daytime because cows try to minimise their body contact with the floor, where the heat from the solar insolation is accumulated (Tapki & Sahin 2006).

According to De Palo et al. (2005) and Provolo and Riva (2009) the cattle react to an increase in THI by spending a longer time standing. This is negative for cows because it hinders the proper blood circulation in their udders (Rulquin & Caudal 1992) and increases the risk of lameness (Cook & Nordlund 2004). The occurrence of heat stress in cows during the H period made it impossible for them to find the optimal location (shade, wet floor, higher air velocity) in which they could lose the excess heat from their bodies into the environment. This resulted in an increase in SC. Cows chose to stand because any physical activity would intensify metabolic heat production and consequently would worsen their comfort (West 2003; Tapki & Sahin 2006). The conducted study confirmed this positive correlation, especially during the daytime in the H period. The cows were standing in the shaded parts of the research area because it was easier for them to cool their bodies down by losing the convective heat (Berman 2005; Maia et al. 2005). Their behaviour was also driven by the fact that during the day the air velocity resulting in the animals’ cooling down was higher than at night. Thus, the increase in THI affected the shortening of the cows’ lying bouts in the cubicles and the lengthening of their lying time in the manure alleys, especially during the daytime.

The total lying time of cows per day is an important indicator of their comfort (Norring et al. 2008). Cows show a strong behavioural need for lying, which is why interfering with this time is very unfavourable for them (Steensels et al. 2012). A decline in LTD in relation to the increasing THI was characteristic for the specified research periods. The total length of the lying bouts for the June–September period given by Brzozowska et al. (2014) amounted to 605 min/d. As a result of the authors’ observations, in the months of June–August the LTD value of 547 min/d was obtained, which means slightly more than 9 h/d. With respect to the overall lying time from 8 to 16 h given by Tucker et al. (2003), in the summer period the total lying time was close to the lower limit. Studies by Cook et al. (2007) showed that the increase in THI from the neutral to hot period resulted in a decrease in lying time from 10.9 to 7.9 h/d. The results obtained by the authors show a decrease in LTD between the N and H periods from 9.9 to 7.8 h/d. Along with the increase in THI by 1 unit between the W and H periods, there was observed a decrease in LTD by 38 min/d in the cubicles, while in the manure alleys it increased by 15 min/d.

The declines in lying bouts’ length demonstrated by Allen et al. (2015) and Kanjanapruthipong et al. (2015) caused by an increase in THI were confirmed by LTH calculated in different areas of the barn. However, it is characteristic that despite very unfavourable conditions in the barn during the period between 12:00 pm and 04:00 pm, the cows staying in the feeding alley returned and lay down in the cubicles. High THI occurring in all the areas impeded the cows’ possibility to rest; however, the desire to lie was stronger. The cattle chose to lie for a short time which, although less comfortable, still provided even a temporal rest.

The negative effect of hot weather and heat stress also manifested itself in a decrease in STEPS, which under neutral temperature conditions mainly depends on the lactation stage, space allowance, free-stall design and bedding (Broucek et al. 2013). The obtained results indicate that during daytime in the W and H periods, the cows STEPS showed a negative correlation with increase of THI. Brzozowska et al. (2014) showed how in the course of the year the cows did the largest number of steps in the period June–September. So divergent conclusions may result from the place of environmental conditions’ measurements. Brzozowska et al. (2014) used the results of the measurements from the meteorological station located in a nearest city in distance of approx. 20 km from the barn.

Conclusions

Cows change their behaviour during the summer depending on the prevailing environmental conditions. The behavioural studies on cows, without taking into
account the variability of microclimate conditions measured in barn, can lead to their inaccuracy and the misrepresentation of their results. THI patterns defining the conditions for cows’ thermal comfort are far from perfect as they only take into account factors affecting air microclimate. However, since cows lie for between 9 and 16 h/d, and over 20 to 30% of their body surface is in contact with the flooring, it would be positive to develop the THI of a flooring, appropriate for a lying down cow.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**References**

Adamczyk K, Górecka-Bruzda A, Nowicki J, Gumulka M, Molik E, Schwarz T, Earley B, Klocek C. 2015. Perception of environment in farm animals – a review. Ann Anim Sci. 15:565–589.

Allen JD, Hall LW, Collier RJ, Smith JF. 2015. Effect of core body temperature, time of day, and climate conditions on behavioral patterns of lactating dairy cows experiencing mild to moderate heat stress. J Dairy Sci. 98:118–127.

Anderson SD, Bradford BJ, Harner JP, Tucker CB, Choi CY, Allen JD, Hall LW, Rungruang S, Collier RJ, Smith JF. 2013. Effects of adjustable and stationary fans with misters on core body temperature and lying behavior of lactating dairy cows in a semiarid climate. J Dairy Sci. 96:4738–4750.

Angrecka S, Herbut P. 2016. Impact of barn orientation on insulation and temperature of stalls surface. Ann Anim Sci. 16:887–896.

Angrecka S, Herbut P. 2017. Eligibility of lying boxes at different THI levels in a freestall barn. Ann Anim Sci. 17:257–269.

Baeta FC, Meador NF, Shanklin MD, Johnson HD. 1987. Equivalent temperature index at temperatures above the thermoneutral for lactating dairy cows. ASAE Paper 87–4015. St. Joseph (MI): American Society of Agricultural and Biological Engineers.

Berman A. 2005. Estimates of heat stress relief needs for Holstein dairy cows. J Anim Sci. 83:1377–1384.

Broucek J, Uhrincat M, Lendelova J, Mihina S, Hanus A, Tancin V, Tongel P. 2013. Effect of management change on selected welfare parameters of cows. Anim Sci Pap Rep. 31:195–203.

Brzozowska A, Łukaszewicz M, Sender G, Kolasińska D, Oprządek J. 2014. Locomotor activity of dairy cows in relation to season and lactation. Appl Anim Behav Sci. 156:6–11.

Cook NB, Nordlund KV. 2004. Behavioral needs of the transition cow and considerations for special needs facility design. Vet Clin North Am Food Anim Pract. 20:495–520.

Cook NB, Mentink RL, Bennett TB, Burgi K. 2007. The effect of heat stress and lameness on time budgets of lactating dairy cows. J Dairy Sci. 90:1674–1682.

De Palo P, Tateo A, Padalino B, Zezza F, Centoducati P. 2005. Influence of temperature-humidity index on the preference of primiparous Holstein Friesians for different kinds of cubicle flooring. Italian J Anim Sci. 4:194–196.

De Palo P, Tateo A, Zezza F, Corrente M, Centoducati P. 2006. Influence of free-stall flooring on comfort and hygiene of dairy cows during warm climatic conditions. J Dairy Sci. 89:4583–4595.

Endres MI, Barberg AE. 2007. Behavior of dairy cows in an alternative bedded-pack housing system. J Dairy Sci. 90:4192–4200.

Fregonesi JA, Veira DM, von Keyserlingk MAG, Weary DM. 2007. Effects of bedding quality on lying behavior of dairy cows. J Dairy Sci. 90:5468–5472.

Galindo F, Broom DM. 2000. The relationships between social behaviour of dairy cows and the occurrence of lameness in three herds. Res Vet Sci. 69:75–79.

Godyń D, Herbut E, Walczak J. 2013. Infrared thermography as a method for evaluating the welfare of animals subjected to invasive procedures – a review. Ann Anim Sci. 13:423–434.

Grant RJ. 2006. Incorporating dairy cow behavior into management tools. Penn State Dairy Cattle Nutrition Workshop; University Park, PA. p. 31–41.

Haley DB, Rushen J, De Passille AM. 2000. Behavioural indicators of cow comfort: activity and resting behaviour of dairy cows in two types of housing. Can J Anim Sci. 80:257–263.

Hempel S, Saha CK, Fiedler M, Berg W, Hansen C, Amon B, Amon T. 2016. Non-linear temperature dependency of ammonia and methane emissions from a naturally ventilated dairy barn. Biosyst Eng. 145:10–21.

Herbut P, Angrecka S. 2014. Ammonia concentrations in a free-stall dairy barn. Ann Anim Sci. 14:153–166.

Herbut P, Bieda W, Angrecka S. 2015. Influence of hygrothermal conditions on milk production in a free stall barn during hot weather. Anim Sci Pap Rep. 33:49–58.

Horky P. 2014. Effect of protein concentrate supplement on the qualitative and quantitative parameters of milk from dairy cows in organic farming. Ann Anim Sci. 14:341–352.

Horky P, Skladanka J, Nevrkla P, Falta D, Caslavova I, Knot P. 2017. Effect of protein concentrate supplementation on the composition of amino acids in milk from dairy cows in an organic farming system. Potr. 11:88–95.

Kadzere CT, Murphy MR, Silanikove N, Maltz E. 2002. Heat stress in lactating dairy cows in a tropical environment. Int J Biometeo. 50:17–22.

Kanjanapruthipong J, Junlapho W, Karnjanasirm K. 2015. Feeding and lying behavior of heat-stressed early lactation cows fed low fiber diets containing roughage and nonforage fiber sources. J Dairy Sci. 98:1110–1118.

Kominkova M, Horky P, Cernei N, Tmejova K, Ruttkey-Nedecky B, Guran R, Pohanka M, Zitka O, Adam V, Kizek R. 2015. Optimization of the glutathione detection by high performance liquid chromatography with electrochemical detection in the brain and liver of rats fed with taurine. Int J Electrochem Sci. 10:1716–1727.

Maia ASC, Da Silva RG, Battiston Loureiro CM. 2005. Sensible and latent heat loss from the body surface of Holstein cows in a tropical environment. Int J Biometeo. 50:17–22.

Mattachini G, Riva E, Provolo G. 2011. The lying and standing activity indices of dairy cows in free-stall housing. Appl Anim Behav Sci. 129:18–27.
Metz JHM. 1985. The reaction of cows to a short-term deprivation of lying. Appl Anim Behav Sci. 13:301–307.

National Research Council. 1971. A guide to environmental research on animals. Washington (DC): National Academy of Science.

Norring M, Manninen E, de Passille AM, Rushen J, Munksgaard L, Saloniemi H. 2008. Effects of sand and straw bedding on the lying behavior, cleanliness, and hoof and hock injuries of dairy cows. J Dairy Sci. 91:570–576.

Osterman S, Redbo I. 2001. Effects of milking frequency on lying down and getting up behaviour in dairy cows. Appl Anim Behav Sci. 70:167–176.

Provolo G, Riva E. 2009. One year study of lying and standing behaviour of dairy cows in a freestall barn in Italy. J Agric Eng. 2:27–33.

Radoč J, Bieda W, Lendelova J, Pogran S. 2014. Computational model of heat exchange between dairy cow and bedding. Comput Electron Agric. 107:29–37.

Rhoads ML, Rhoads RP, VanBaale JJ, Collier RJ, Sanders SR, Weber WJ, Crooker BA, Rulquin H, Caudal JP. 1992. Effects of lying or standing on mammary blood flow and heart rate of dairy cows. Annales De Zootechnie. 41:101.

Rulquin H, Caudal JP. 1992. Effects of lying or standing on mammary blood flow and heart rate of dairy cows. Ann Zootech. 41:101.

Sejian V, Malik IH, Soren PK, Mech NM, Mishra A, Ravindra JP. 2015. Chapter 3: Strategies for alleviating abiotic stress in livestock. In: Malik PK, Bhatta R, Takahashi J, Kohn RA, Prasad CS, editors. Livestock production and climate change. Wallingford: CABI Publishing; p. 25–60.

Steensels M, Bahr C, Berckmans D, Halachmi I, Antler A, Maltz E. 2012. Lying patterns of high producing healthy dairy cows after calving in commercial herds as affected by age, environmental conditions and production. Appl Anim Behav Sci. 136:88–95.

Tapki I, Sahin A. 2006. Comparison of the thermoregulatory behaviours of low and high producing dairy cows in a hot environment. Appl Anim Behav Sci. 99:1–11.

Thom EC. 1959. The discomfort index. Weatherwise. 12:57–60.

Tolkamp BJ, Haskell MJ, Langford FM, Roberts DJ, Morgan CA. 2010. Are cows more likely to lie down the longer they stand? Appl Anim Behav Sci. 124:1–10.

Tousova R, Duchacek J, Stadnik L, Ptacek M, Pokorna S. 2017. Influence of temperature-humidity relations during years on milk production and quality. Acta Univ Agric Silvic Mendel Brun. 65:211–218.

Tucker CB, Weary DM, Fraser D. 2003. Effects of three types of free-stall surfaces on preferences and stall usage by dairy cows. J Dairy Sci. 86:521–529.

Vasseur E, Rushen J, Haley DB, de Passillé AM. 2012. Sampling cows to assess lying time for on-farm animal welfare assessment. J Dairy Sci. 95:4968–4977.

West JW. 2003. Effects of heat-stress on production in dairy cattle. J Dairy Sci. 86:2131–2144.