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HEAT LOAD-INDUCED CHANGES IN LYING BEHAVIOR AND LYING CUBICLE OCCUPANCY OF LACTATING DAIRY COWS IN A NATURALLY VENTILATED BARN*

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Abstract

Dairy cows show a high sensitivity to changes in barn climate, which can result in physiological and ethological responses because of the homeostatic mechanisms to regulate the body temperature under heat load. The objective of this study was to analyze the lying behavior and occupancy of lying cubicles of lactating high-yielding Holstein-Friesian cows throughout the day during three summer months and three winter months. The study was conducted in summer 2016 and in winter 2016/17 in a naturally ventilated barn in Brandenburg, Germany. The determined temperature-humidity index (THI) of the barn was calculated using the measured ambient temperature and relative humidity at eight locations inside the barn. The THI was used to define the heat load the cows were exposed to. The activity of the cows was measured with accelerometers, and a video recording was made to analyze the occupancy of the three rows of lying cubicles. The results indicated that increasing heat load led to a decrease in lying time; therefore, the daily lying time differed between summer and winter months. In addition, there were different patterns of lying behavior during the course of the day, depending on the season. A sharp decline in lying time could be observed especially in the afternoon hours during the summer. The occupancy of lying cubicles was also influenced by the heat load. The data could be helpful to enable evaluation with algorithms for early detection of heat load.

Key words: dairy cow, temperature-humidity index, heat load, lying time, lying cubicle occupancy

Comprehensive knowledge and analysis of the causes of behavioral change constitute the basis for improving quality of animal husbandry and welfare for cows.

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One of the behavioral characteristics which is an indicator of cows' physiology and state of health is the length of their lying time (Angrecka and Herbut, 2017; Tolkamp et al., 2010). Whereby, it should be recognized that the lying time varied among cows because of animal individual differences. Previous studies showed an increased lying time associated with increased parity, later stage of lactation and higher body condition score (Bewley et al., 2010; Maselyne et al., 2017; Westin et al., 2016). Also, the locomotion score influenced the lying time. Lame cows lie down longer (Westin et al., 2016). On commercial farms, 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 load, which causes a reduction in lying time (Anderson et al., 2013; Heinicke et al., 2018). Suboptimal barn climate, with respect to thermal environment, can place a significant heat load on dairy cows.

The high productivity of dairy cows contributes to the production of large amounts of metabolic heat that must be discharged from the cow's body into the environment (Godyń et al., 2019). However, high air temperatures and high relative humidity impede this process, and the cow's body temperature increases (Allen et al., 2015). This may result in impaired thermoregulation and excessive heat load (Rhoads et al., 2009). The first way for the cows to cope with heat load is behavioral change, which includes either searching for shade or decreasing duration of lying bouts to increase available surface for heat dissipation (Allen et al., 2015; Anderson et al., 2013; Smith et al., 2016). This was also confirmed in research performed by Cook et al. (2007), in which under increasing THI daily lying time was reduced by 3 h. Cows show strong behavioral need to lie while resting; they spend 8 to 15 h daily on average in a lying position. Reducing the lying time has a negative impact on cows' welfare and milk yield (Tucker and Schütz, 2009).

The present study aimed to analyze the lying behavior of lactating high-yielding Holstein-Friesian cows throughout the day (time interval of 3 h) during the summer and the winter, including the occupancy of lying cubicles, in a naturally ventilated barn, which included mechanical cross ventilation (three fans). We assumed that the daily pattern of lying behavior and occupancy of the lying cubicles change with increasing heat load as a consequence of the thermal environment. Visual observations were the reason for our hypotheses that there are differences in lying time depending on the season, and that the lying cubicles were used significantly different because of the temperature-humidity index (THI) within the barn. The study should contribute that early detection of changes in behavior could allow prompt action to optimize barn climate.

Material and methods

The study was conducted for three summer months (21/06/2016 to 21/09/2016) and for three winter months (21/12/2016 to 19/03/2017) in a naturally ventilated dairy barn with a loose housing system including mechanical ventilation. The barn was located in Eastern Germany, Brandenburg (approximately 56 km west of Berlin, coordinates: 52°23'47.4"N, 12°46'02.8"E, 32 m above sea level), in typical moderate climate.

The barn (Figure 1) was equipped with 51 lying cubicles of which 17 single lying cubicles were at the open side of the barn (A), and 17 double lying cubicles consisting of paired cubicles (head to head) oriented toward the middle (B) and toward the feeding table of the barn (C).

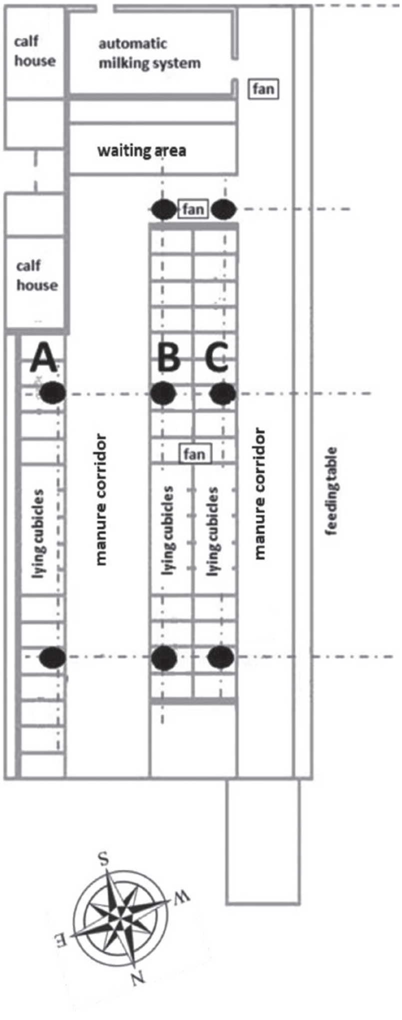

Figure 1. Layout of the naturally ventilated dairy barn (including mechanical cross ventilation – three fans) with the identification of the three rows of lying cubicles (A – open side, B – middle, C – feeding table). The black dots show the locations of the climate sensors

The lying cubicles (235 x 115 cm) were bedded with a mixture of straw and lime, and had enough freedom of movement for the head when getting up. The cleaning of the cubicles from feces happened twice a day and new bedding was dispersed once a week. Additionally, the barn was equipped with an automatic milking system (Lely Astronaut A4, Maassluis, The Netherlands), and a fan system with cross ventilation.

Two fans were installed above the double lying cubicles, and one fan was above the feeding area. They were manually controlled by the herd manager. In the barn, there were no door systems and the cows could move freely. The cows were fed twice a day at 6:30 am and 9:30 am with a total mixed ration. The remaining feed was moved into position before feeding at 9:00 am, at 12:00 am, at 15:30 pm, at 17:00 pm and at 20:00 pm. The herd consisted of 51 Holstein-Friesian cows (first to eighth lactation), which had an average daily milk yield of 40.7 ± 6.8 kg per cow and the number of daily milkings was 2.4 ± 0.5 times per cow. The herd was a high-yielding group, and cows dropped below 30 kg milk per day left the group and were exchanged by a new cow with fewer days in milk and therefore more milk yield mostly. During the experimental period, the health status (especially locomotion score and udder health) of the cows was constantly evaluated.

The ambient temperature and relative humidity within the barn were automatically measured at eight locations every 10 min using EasyLog USB 2+ sensors (Lascar Electronics Inc., Erie, Pennsylvania, USA). In this study, the THI based on the formula of NRC (1971) was applied:

$$THI = (1.8\times T+32) - (0.55-0.0055\times RH)\times(1.8\times T-26)$$

where: T is the dry bulb temperature in °C, and RH is the relative humidity in %. The THI was used as a measure of the climatic environment experienced by the cows inside of the barn and defined the heat load the cows were exposed to. The heat load threshold of 68 THI by Zimbelman et al. (2009) was used. A two-factorial ANOVA was conducted at a significance level of 0.05 to test if there were differences in THI, T and RH, respectively, between the rows of lying cubicles (A, B, and C) while also considering the seasons (summer and winter). The interaction of both factors was initially considered but was found to be not significant and was therefore excluded from the ANOVA model. In this respect, we averaged the THI values across all eight locations in the barn and used the average values to describe the climate conditions.

The activity of the dairy cows was recorded with an IceTag3D™ accelerometer sensor (IceRobotics, Edinburgh, UK) on one hind leg of each cow. More details on the activity measurements are described by Heinicke et al. (2018).

To determine occupancy rates of the three rows of lying cubicles (A, B, C), a system of two cameras (Dome camera WV-CW364, Panasonic Marketing Europe GmbH, Hamburg, Germany) was installed above the lying cubicles. The video data were recorded from 4 am to 10 pm and prepared by time sampling of 30 min (Chen et al., 2016).

The following data per season were calculated from the measurements:
- average THI per time interval (3 h),
- average lying duration per time interval (3 h),
- percentage occupancy of lying cubicles per 30 min.

The occupancy of lying cubicles was defined as the number of cows lying down into the cubicles of the respective rows (A, B, C). The maximal number of occupied lying cubicles per row was 17 cows, this corresponds to an occupancy of lying cubicles of 100%. The percentage occupancy of the lying cubicles P was estimated using a generalized linear model with a binominal distribution and a logit link function:

$$logit(p) = \eta = log\left(\frac{p}{(1-p)}\right)$$

$$logit^{-1}(\eta) = \frac{1}{1 + exp(-\eta)}$$

The linear predictor η was as follows:

$$\eta ij = \mu + R_i + xTHI + x_iTHI + \varepsilon_{ij}$$

with μ as the general mean, R_i as the effect of the i-th cubicle row, x as the regression coefficient for *THI*, x_i as the regression coefficient for *THI* specific for the i-th cubicle row R and the random residual ε for the j-th half-hour time span. The season and the time of day showed no significant effects on the percentage occupancy of the lying cubicles and were therefore excluded from this model.

The statistical analyses and the preparation of the figures were carried out with SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

The average THI during the three summer months and the three winter months were 67.5 ± 3.8 THI and 41.4 ± 6.4 THI, respectively. There were significant differences in THI between the seasons (P<0.001). Figure 2 shows the fluctuations over the course of the day, with THI increasing during the afternoon in summer as well as in winter. On average, the lowest THI occurred at approximately 4 am. In the summer the threshold of 68 THI was exceeded, especially during afternoon hours. In the analysis of the results, only clinically healthy animals with locomotion score less or equal two were integrated. The average daily lying time per cow was 10.3 ± 1.1 h in summer and 11.4 ± 1.1 h in winter (Figure 2).

The data from the video analysis concerning the occupancy of the lying cubicles showed pronounced differences in occupancy between summer and winter months. Occupancies of the three rows of lying cubicles varied from approximately 0–60% during the period from 4 am to 10 pm. Figure 3 supports the result of reduced lying time during the afternoon by the decline in percentage occupancies of the lying cubicles in all three rows during the summer months. The two sharp decreases in occupancy of lying cubicles in the morning may be attributed to the feeding times at 6:30 am and 9:30 am. Table 1 shows the percentage of lying cows within the three rows of cubicles, and the data are ordered by increasing average THI values. The lying cubicles in the middle of the barn (B) were the most frequently used cubicles under barn climate conditions between 25 and 65 THI. The least used cubicles were the lying cubicles near the feeding table of the barn (C) under barn climate conditions between 25 and 45 THI. The occupancy of cubicle row C increased with increasing THI. The visual observation implied that the cubicle row C had the highest air movement and the cubicles were in the shade at all times. The occupancy of the lying cubicles at the open side of the barn (A) declined in percentage of lying cows when THI was elevated. Here, the solar radiation increased until noon because of the orientation of the barn to the world's sides, and the fans were installed too far central on the barn so that the ventilation in the row A was not available.

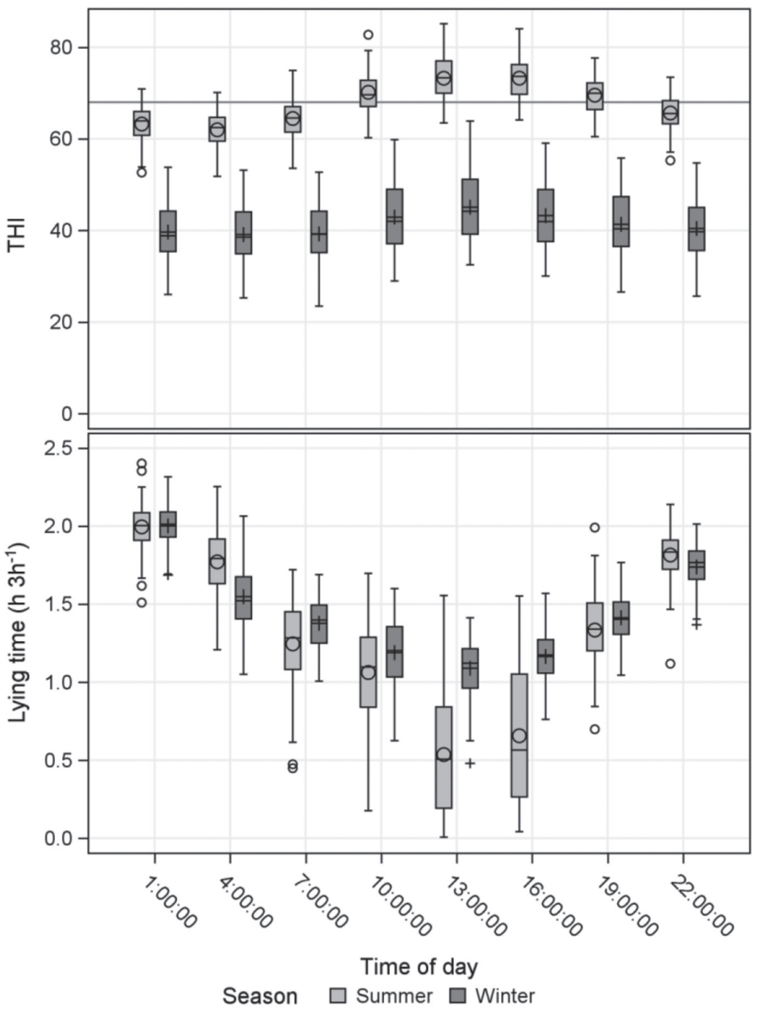

Figure 2. Temperature-humidity index (THI) with the reference line for the heat load threshold of 68 THI, and lying time (h 3 h^{-1}) over the course of the entire day, categorized by seasons summer and winter. Data basis were the climate and accelerometer data

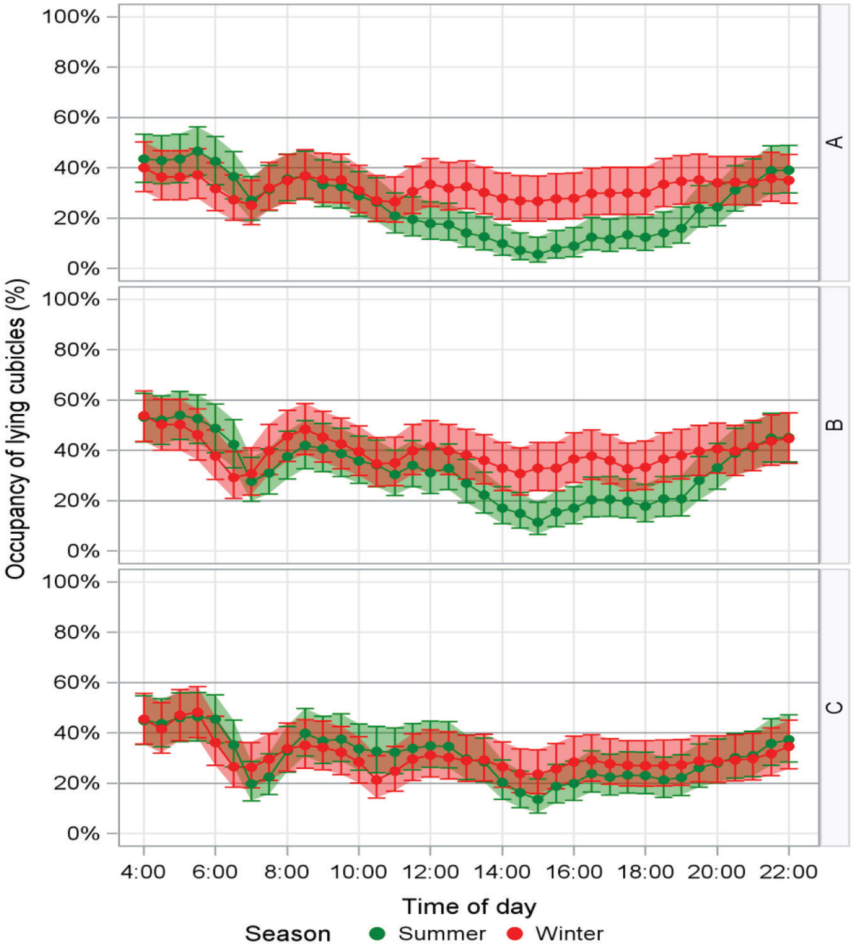

Figure 3. Percentage occupancy (mean, standard deviation) of the three rows of lying cubicles (A – open side, B – middle, C – feeding table) over the course of the day from 4 am to 10 pm, categorized by seasons summer (green) and winter (red). Data basis were the video data

Table 1. Percentage of lying cows within the three rows of lying cubicles under different levels of average temperature-humidity index (THI), based on the results of the linear predictors:

A: $\eta = -0.9966^{\dagger} + 0.6561^{\dagger} + 0.002646 \times \text{THI} - 0.01448^{\dagger} \times \text{THI}$

B: $\eta = -0.9966^{\dagger} + 0.9006^{\dagger} + 0.002646 \times \text{THI} - 0.01263^{\dagger} \times \text{THI}$

C: $\eta = -0.9966^{\dagger} + 0 + 0.002646 \times \text{THI} + 0 \times \text{THI}$

† Parameter estimate is different from zero (t-Test, significance level of 0.05)

Average THI	Row of lying cubicles	Mean percentage of lying cows	95% confidence interval limits for the mean percentage
1	2	3	4
25	A	34.61 ab	[29.11; 40.55]
	B	41.44 b	[35.75; 47.38]

Table 1 – contd.

1	2	3	4
	C	28.28 a	[23.40; 33.74]
35	A	31.98 a	[28.06; 36.17]
	B	39.04 b	[34.91; 43.34]
	C	28.82 a	[25.10; 32.86]
45	A	29.46 a	[26.76; 32.32]
	B	36.69 b	[33.79; 39.70]
	C	29.37 a	[26.64; 32.26]
55	A	27.06 a	[24.82; 29.44]
	B	34.41 b	[31.99; 36.91]
	C	29.92 a	[27.61; 32.34]
65	A	24.79 a	[22.13; 27.66]
	B	32.19 b	[29.28; 35.24]
	C	30.48 b	[27.64; 33.47]
75	A	22.65 a	[19.23; 26.49]
	B	30.05 b	[26.19; 34.21]
	C	31.04 b	[27.08; 35.30]
85	A	20.65 a	[16.48; 25.54]
	B	27.99 ab	[23.14; 33.42]
	C	31.61 b	[26.30; 37.45]

Different small letters (a, b, c) in the same row for each comparison show significant differences (simulation-adjusted P for multiple pairwise comparisons ≤0.05).

Discussion

Zimbelman and Collier (2011) found that physiological and production parameters indicated a THI threshold of 68 THI at which lactating dairy cows (producing more than 35 kg d^{-1}) suffered adverse effects from heat load. Based on this report, times during the three experimental months in summer when climatic conditions exceeded the threshold of 68 THI may be regarded as periods of heat load for the cows.

Potential existing heterogeneity of the barn climate could not be determined in the present study regarding the ambient temperature, relative humidity and THI. Another study which deals with a similar topic found significant differences in temperature, humidity and air movement inside a free stall barn during heavy frost (Herbut, 2013). Unfortunately, the present study did not measure the air movement and the solar radiation which would be very important to explain and discuss the lying behavior of the cows regarding the existing topic (Angrecka and Herbut, 2016; Angrecka et al., 2017).

Similarly to the presented results, Brzozowska et al. (2014) and Steensels et al. (2012) observed that the season of year was one factor which had a significant impact on activity parameters of cows. Cows spent more time lying down in winter than in other seasons. Several studies reported that cows under heat load spent more time in a standing posture to improve the wind convection and evaporation by heat output because of the increase of the effective body surface (Berman, 2005; Tucker et al., 2008). In particular, the straw bedding used in the presented study might increase the heat load in lying cows, as observed by Angrecka and Herbut (2016, 2017).

Previous studies have demonstrated that comparison of activity at different hours of the day shows a strong diurnal pattern, while behavior at the same hours of different seasons only differs significantly during daylight hours, despite the differences in temperature (Provolo and Riva, 2008). Similarly, Herbut and Angrecka (2018) found that the analysis of proportions of cows lying down during night-time and day-time showed strong correlations with the change in THI-value. Elevated THI was associated with a reduced percentage of cows lying down. Endres and Barberg (2007) observed the greatest percentage of time spent lying to be at 3 am. Peak lying times were determined to be from 8 pm to 4 am. The presented results implied this.

Furthermore, the results were consistent with findings of Angrecka and Herbut (2017), who recognized that, regardless of the THI value, double box areas were predominantly occupied, whereas single box areas were less frequently used. Double box areas were also commonly used by cows during the hot period, but there was a negative correlation between the level of THI with when there were cows lying down and the length of their lying down bouts in double boxes.

In future studies, additional measurements of air movement and solar radiation must be included to optimize the analysis regarding the preferred locations of the cow under heat load in the barn. Moreover, cow individual differences (e.g. lactation number, lactation stage) should be considered (Maselyne et al., 2017; Westin et al., 2016). Another restriction in the experimental design could be that the number of lying cubicles should be higher than the number of cows in order to maintain freedom of choice. This was not possible because of the herd management of the used dairy farm. In addition, the selectivity of the cubicles is linked to the hierarchy in the herd. On account of the time-consuming video analysis it seems to be helpful to use a tracking system, which makes it possible to determine and evaluate the locations of the animals automatically and individually.

Conclusion

In conclusion, the lying behavior and the occupancy of the lying cubicles depend on the climatic conditions within the dairy barn. In further studies, the climate factors like solar radiation and air movement should be additionally considered in the models especially regarding the occupancy of the lying cubicles. The two analyzed traits of the lying behavior could be used to compare the effect of different ventilation systems with regard to heat load reduction for the cow maybe. Otherwise, the obtained data could be helpful to enable evaluation with algorithms for early detection of heat load.

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