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The effect of hutch compass direction on primary heat stress responses in dairy calves in a continental region

M Bakony†, G Kiss†‡, L Kovács§ and V Jurkovich†*

† Department of Animal Hygiene, Herd Health and Mobile Clinic, University of Veterinary Medicine, Istvan Utca 2, 1078 Budapest, Hungary
‡ Extra Milk Ltd, Beled, Hungary
§ Institute of Animal Sciences, Hungarian University of Agriculture and Life Sciences, Kaposvár, Hungary
* Contact for correspondence: bakony.mikolt@univet.hu

Abstract

Heat stress reduction in hutch-reared dairy calves is overlooked on most dairy farms. We hypothesised that during summer, the microclimate within hutches is directly affected by compass direction as a result of differences in exposure to solar radiation. On a bright, mid-August day a number of behavioural and physiological heat stress response measures (respiratory rate, body posture, being in the shade or sun) were recorded in 20-min intervals from 0720–1900h on calves housed in hutches with entrances facing all four points of the compass. In conjunction with this, dry bulb (ambient) and black globe temperatures, and wind speed were recorded both inside the plastic hutches and at one sunny site at the exterior. Data were compared in terms of distinct periods of the day (0720–1100, 1120–1500, 1520–1900h). Dry bulb temperatures were higher inside hutches compared to outside while for black globe temperatures the opposite was true. Daily average temperatures and respiratory rates did not differ between hutches facing different compass points. In the morning and afternoon, hutch temperature and calf respiratory rate differed relative to compass point. Calves in east- and north-facing hutches were seen more in the shade than those in south- and west-facing ones. Our conclusion was that in a continental region having hutch entrances face towards the east or north confers some advantages in mitigating severe solar heat load in summer.

Keywords: *animal welfare, black globe temperature, calves, heat stress, hutch compass direction, solar radiation*

Introduction

In Europe and North America it tends to be the case that dairy calves, for the first few weeks of their lives, are housed outdoors in individual hutches that feature a small, fenced outdoor area (Roland *et al* 2016). These were traditionally made from plywood before being replaced by fibreglass-reinforced plastic and, more recently, various types of polyethlyene. Plastic hutches provide an unquestionable advantage when it comes to hygiene; however, thermally, plastic and fibreglass are at a distinct disadvantage compared to plywood (Lammers *et al* 1996). While plastic hutches offer reasonable protection from the cold, they provide minimal protection from the impact of direct solar radiation (Lammers *et al* 1996).

At ground level, solar radiation is heavily influenced by the movement of the sun and, as such, greater solar radiation was observed in a north-south compared to an east-west orientation, in a greenhouse tunnel study (Wang & Boulard 2000). Solar irradiation and angle of incidence can increase the temperature of a variety of materials, including metals (Kordun 2015), wood (Castenmiller 2004) and glass or plastic (Santos & Roriz 2012; Wong & Eames 2015). Such is the thermal conductivity of certain types of artificial polymers that they are able to substitute for metal in solar collectors (Ariyawiriyanan *et al* 2013). Of course, plastics used for blow moulding are not thermoplastics; however, there is great variability in their thermal conductivity (Yang 2007). The thermal efficiency of plastics is influenced by the solar incidence angle with the greatest efficiency occurring when the panel is oriented to the south, and tilted at an acute angle (Ariyawiriyanan *et al* 2013). Conventional fibreglass hutches are still in use in many Hungarian dairies. Fibreglass-reinforced plastic tends to heat up due to exposure to solar radiation and the absorbed heat is irradiated to the hutch environment, causing the inner temperature to rise. Despite heat stroke in newborn calves occurring only sporadically, research into heat stress in outdoor-kept calves is still advised. Cold stress is subjected to far more research attention compared to the effects of high dry bulb (ambient) temperature (DBT) (Roland *et al* 2016).

The upper critical temperature in dairy calves has not been clearly defined, but most researchers agree on 26°C (Spain & Spiers 1996; Collier *et al* 2019). The dearth of research-based evidence, however, often ensures the impact of heat stress passes unnoticed. *In utero* heat stress can lead to an altered growth pattern and a tendency for reduced milk yield, amongst others (Tao & Dahl 2013). However, heat stress abatement in pre-weaning calves remains neglected on most dairy farms. Our assertion was that on particularly sunny days the compass direction the hutch entrance faces could have an effect on hutch microclimate and calves' primary heat stress responses. This compass direction would also potentially affect the availability of shaded resting areas both inside and outside the hutch. The amount of radiant heat able to be absorbed into hutch materials is directly influenced by the solar incidence angle as well as the duration of exposure, and both can vary depending on which compass point the hutches are oriented toward. The black globe temperature (BGT) is commonly used to determine the extent to which thermal radiation modifies the sensible heat content of the environment. It is measured via a dry bulb thermometer placed at the centre of a dark-coloured hollow metal sphere and the temperature measured integrates the amount of radiant heat absorbed by the shell. Where the latent heat content of the animals' environment (in particular, solar radiation) is expected to modify total heat exchange, it is advised that BGT is used instead of DBT (Hahn *et al* 2009). Although the use of the temperature humidity index (THI) is widespread to assess the thermal environment, we decided not to use it here, for two main reasons. First, the THI is the weighted average of DBT and relative humidity. It was originally developed for humans and later used in animal studies, mostly in cases of lactating dairy cows in stabled environments. Currently there are several different equations for calculating the THI (Bohmanova *et al* 2007). We have no accurate knowledge as to how relative humidity affects the thermal perception of pre-weaning calves, therefore no clear idea what would be an appropriate weighting factor. Second, it has been shown earlier that DBT has a stronger correlation with the heat stress response of dairy calves compared to most of the THIs commonly used for the assessment of thermal stress in pre-weaning calves (Kovács *et al* 2018c). The directional alignment of hutches could serve as a no-cost measure for improving the thermal environment and, thus, the welfare of calves. In our study, we aimed to monitor temperature conditions as well as primary behavioural and respiration responses of dairy calves in differently oriented calf hutches. The assumption being that orientation would show an influence on climatic conditions within hutches, and that differences would emerge primarily between east- or north-facing hutches and those facing to the south or west.

Materials and methods

Study animals and measurements

A commercial dairy farm in Beled, Hungary (47°28'09.3"N 17°04'14.6"E) was chosen as the site to take measurements since the design of the study fitted well with their regular daily routines. The farm's population consisted of approximately 900 Holstein Friesian cows and their offspring. Calves remained outdoors from birth until weaning (mean: 60 days; min–max: 56–70 days) in individual, fibreglass-reinforced polyester hutches (Agrobox-1, Agroplast Ltd, Gyál, Hungary) containing an adjacent, fenced outdoor area (henceforth referred to as the 'outdoor area'), placed on pebble-stone and bedded with straw both inside the hutch and in the outdoor area. Measurements took place between 0720 and 1900h on the 22 August 2018 which was a bright and sunny day. Twenty occupied hutches were chosen for testing, five of which faced each of the four points of the compass and all were situated away from any trees and buildings to ensure no shade impinged on the study site. All the calves in the study were female and aged between 7–17 days. Four empty hutches (each with openings facing a different point of the compass) were used for recording climatic parameters (DBT, BGT, and wind speed) in 20-min intervals from 0720–1900h. The same outdoor area parameters were measured at one sunlit site outside the hutches, an area representative of all hutches' outdoor areas. Climatic measurements were taken using a Kestrel 5400AG Cattle Heat Stress Tracker (Nielsen-Kellerman Co, Boothwyn, PA, USA) for hutches facing east and west and outside the hutches, and with a Testo 480 (Testo SE & Co KgaA, Lenzkirch, Germany) for hutches facing the south and north. Measurement accuracy of both types of devices were similar enough to allow direct comparisons. Thermometers were placed inside the hutches at the approximate height of the head of a lying calf (30–40 cm above the ground). The outside thermometer was situated 1.5 m above the ground in an open area exposed to the sun. In conjunction with temperature measurements, respiration rates (RR) were taken at 20-min intervals by counting flank movements (for 30 s and multiplying by 2) from a distance of 3.5–4 m to avoid causing disturbance to the calf. At the same time, it was also recorded whether the calves were inside or outside the hutch, lying or standing and exposed to mainly sun or shade. Hereafter, location preference, body posture and exposure to the sun or shade will be referred to as behavioural measures. Periods immediately prior to feeding, when calves were alert and excited, were not included in data collection.

Statistical analysis

In order to best characterise the temperature conditions for hutches facing towards different points of the compass, different periods of the day were categorised, namely morning (0720–1100h), midday (1120–1500h) and afternoon (1520–1900h). Mean temperatures were compared for points of the compass and periods of the day using variance analysis.

Daily average RR values were compared by fitting a linear mixed model with compass direction and location as the independent variables and calf as a random term. In another model, the period of the day was also included as an explanatory variable to assess time-related differences between compass directions.

To study the measure of association between temperatures and RR, a general linear mixed model was fitted with RR as the dependent variable and BGT/DBT, compass direction, period of

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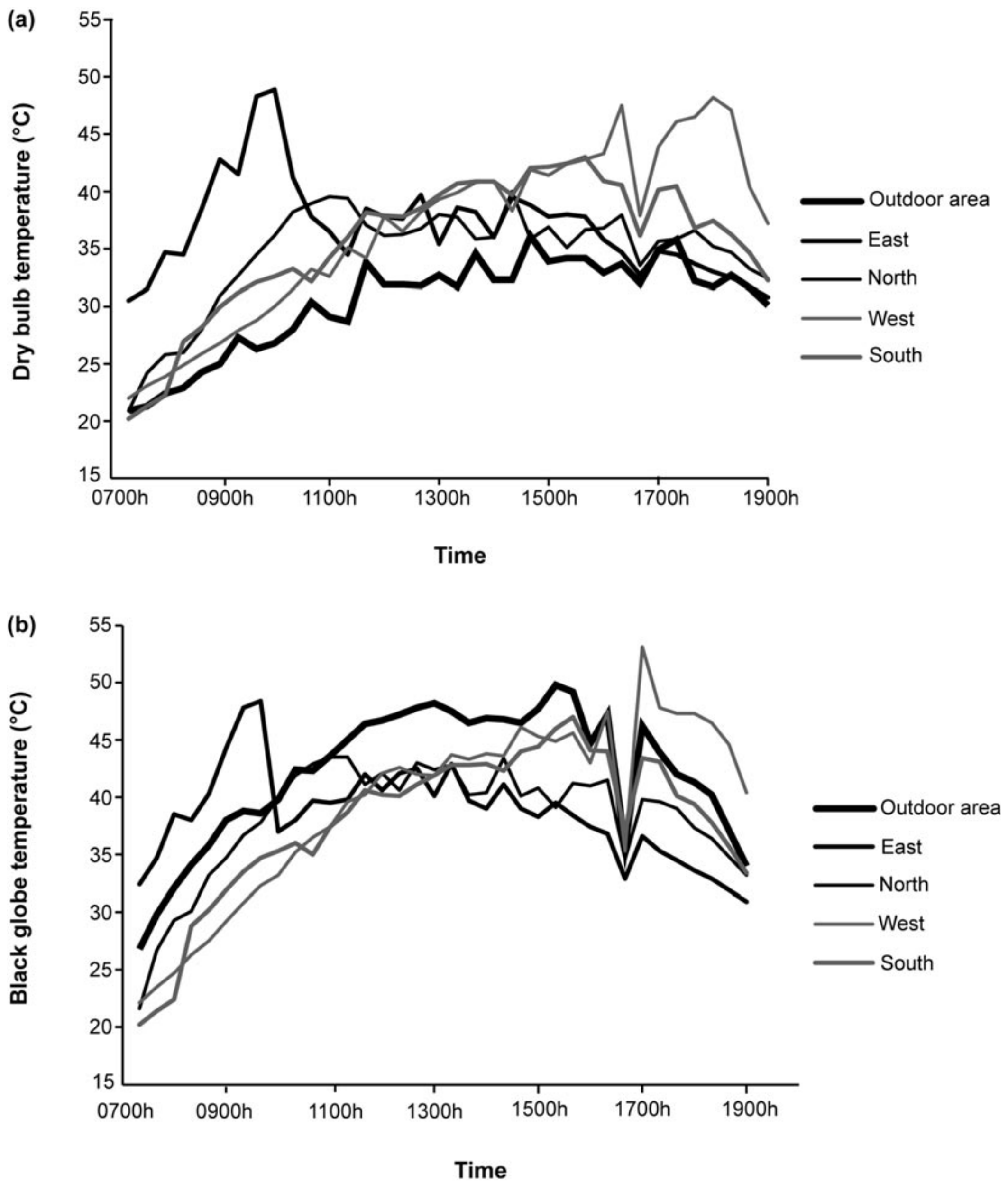
Figure 1



Temporal pattern of changes in the (a) dry bulb and (b) black globe temperatures (°C) measured at 20-min intervals between 0700 and 1900h inside hutches with entrances facing all four points of the compass (north, south, east and west) and at a site in the sun, in the Outdoor area.

the day and their interactions as independent variables, with calf ID as a random term. Model selection was based on removing non-significant terms to achieve the lowest Akaike information criterion. Behavioural measures were dichotomised and compared using generalised linear mixed models. Compass direction, the period of the day and their interaction were included as explanatory variables and calf as a random term. Multiple comparisons were made using the Bonferroni correction method. The level of significance in all tests was set to $P < 0.05$. All statistical analyses were performed using the R statistical programme (R Core Team 2019).

Results and discussion

Climatic parameters

Average wind speed was 0.07 m s^{-1} (min: 0.02 m s^{-1}; max: 0.8 m s^{-1}) in hutch environments and 0.79 m s^{-1} (min: 0 m s^{-1}; max: 1.6 m s^{-1}) in the outdoor area. In the study of Dado-Senn *et al* (2020), an air velocity of 2 m s^{-1} provided active cooling for calves; thus, we regarded the wind speed in our study as not influencing the thermal comfort of the calves. DBT and BGT at each time-point are displayed in Figure 1.

Table 1 Mean (± SD) black globe (BGT) and ambient (DBT) temperature measured inside hutches facing four compass points (east, north, south and west) and in a sunlit site (Outside) and respiratory rate (RR; breaths per min) of calves (n = 5 per compass direction) located inside (ins) or outside (outs) the hutch at the time of observation.

Time of observation	Measure	East	North	South	West	Outside
Daily	BGT	38.5 (± 4.1)^{ab}	38.2 (± 5.1)^{ab}	37.7 (± 7.7)^{a}	39.3 (± 7.9)^{ab}	41.2 (± 5.9)^{b}
	DBT	36.9 (± 4.2)^{a}	34.5 (± 4.5)^{a}	35.5 (± 6.1)^{a}	36.6 (± 7.5)^{a}	30.3 (± 4.2)^{b}
	RR (ins)	97.9 (± 22.2)	96.9 (± 29.3)	107.5 (± 30.1)	108.3 (± 28.7)	
	RR (outs)	77.9 (± 19.9)	80.9 (± 21.2)	91.9 (± 25.1)	85.2 (± 26.1)	
Morning	BGT	39.9 (± 4.8)^{a}	34.9 (± 6.9)^{ab}	30.6 (± 6.0)^{b}	29.9 (± 5.1)^{b}	36.8 (± 5.2)^{a}
	DBT	38.9 (± 5.9)^{a}	31.3 (± 6.3)^{b}	28.7 (± 4.9)^{bc}	27.6 (± 3.7)^{bc}	25.4 (± 3.1)^{c}
	RR (ins)	86.0 (± 25.9)^{a}	60.7 (± 19.4)^{b}	81.9 (± 23.9)^{ab}	66.0 (± 14.6)^{ab}	
	RR (outs)	81.3 (± 21.5)	75.2 (± 21.5)	76.0 (± 24.1)	70.1 (± 14.6)	
	BGT	40.6 (± 1.5)^{a}	41.7 (± 1.3)^{ab}	41.8 (± 1.7)^{ab}	42.9 (± 1.8)^{b}	46.9 (± 0.8)^{c}
Midday	DBT	37.7 (± 1.6)^{ab}	37.2 (± 1.4)^{a}	39.5 (± 1.8)^{b}	38.7 (± 2.5)^{ab}	32.6 (± 1.8)^{c}
	RR (ins)	104.3 (± 16.7)	109.4 (± 22.1)	120.2 (± 23.5)	111.6 (± 20.7)	
	RR (outs)	90.7 (± 10.1)	93.0 (± 11.5)	110.7 (± 34.5)	98.0 (± 26.2)	
Afternoon	BGT	35.1 (± 2.7)^{a}	38.1 (± 2.8)^{ab}	40.9 (± 4.3)^{bc}	45.2 (± 4.4)^{c}	42.6 (± 5.1)^{bc}
	DBT	34.2 (± 2.2)^{a}	35.3 (± 1.6)^{a}	38.4 (± 3.3)^{b}	43.6 (± 3.7)^{c}	33 (± 1.6)^{a}
	RR (ins)	96.6 (± 23.8)^{a}	106.3 (± 22.9)^{a}	117.5 (± 27.1)^{ab}	128.2 (± 19.2)^{bc}	
	RR (outs)	74.3 (± 19.1)	74.4 (± 25.7)	99.2 (± 20.3)	94.5 (± 28.0)	

Observation times: morning 0720–1100h; midday 1120–1500h; afternoon 1520–1900h;
Means with different superscripts indicate significant differences within a row at $P < 0.05$.

In the early morning hours, both BGT and DBT moved in a similar range in all hutches. In the early afternoon hours, temperatures in the east- and north-facing hutches began to decrease. In contrast, those measured in the south- and west-facing hutches continued to increase. The separation of temperature curves would suggest that the south- and west-facing hutches were exposed to greater solar radiation in the afternoon. BGT were higher in the outdoor area compared to BGT inside the hutches, with the exception of east-facing hutches in the morning and west-facing hutches in the afternoon. Interestingly, DBT in the outdoor area were virtually always lower than DBT measured inside the hutches.

For comparison of the total heat load and within different periods of the day, mean, minimum and maximum BGT and DBT values are expressed in Table 1. Daily mean BGT measured inside the hutches did not differ from the outdoor area, apart from south-facing hutches in which inside temperatures were lower. This would suggest that hutch material provides minimal resistance to solar radiation as well as indicating that the direction a hutch entrance faces does not influence calves' overall daily heat load. However, significant differences were found when temperatures from different periods of the day were compared, suggesting that even although overall heat load did not differ between points of the compass, the temporal distribution can be variable.

In the morning period, the BGT in the east-facing hutches was, on average, 9.5°C higher ($P < 0.0001$), and the temperature in the outdoor area 6.5°C higher ($P < 0.05$) than both in south- and west-facing hutches.

In the midday period, BGT was, on average, 4–6°C higher outside than inside hutches facing all four compass points ($P < 0.0001$). A 2.2°C average difference was also found between east- and west-facing hutches ($P < 0.01$).

In the afternoon period, the lowest BGT were measured in east-facing hutches. It was, on average, 7.5°C lower than outside ($P < 0.001$) and 5 and 10°C lower than in south- and west-facing hutches, respectively ($P < 0.01$). Black globe temperature inside north-facing hutches was also lower than inside west-facing hutches by an average of 7.1°C ($P < 0.001$). Temperature conditions did not differ between south- and west-facing hutch interiors and outside. The underlying reason for differences between periods of the day is the daily solar incidence angle pattern. In the hours of the morning, the BGT sensor in the east-facing hutch was exposed to the full sun. Therefore, heat irradiated by the hutch material as well as heat conveyed by solar radiation was being measured. Before sunset, the same is true for the sensor in the west-facing hutch in the afternoon hours. If the thermometer is exposed to the full sun, it also suggests that the hutch provides no shading for the calf. It follows that

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those calves in east-facing hutches had no access to shade in the morning hours. In contrast, calves in west-facing hutches had no access to shade in the afternoon hours. In both instances, inside temperatures exceeded the BGT measured outside during the same period.

Daily mean DBT were similar between hutches facing different compass points. Hutch inside averages were 4.2–6.4°C higher than the temperature of the outdoor area ($P < 0.01$).

In the morning, DBT in east-facing hutches was, on average, 7.5°C higher than in north-facing hutches ($P < 0.01$) and 10–13.5°C higher than in the south- and west-facing hutches and the outdoor area, respectively ($P < 0.0001$). The 6°C difference between north-facing hutches and outdoor area temperature was also significant ($P < 0.05$).

In the midday period, temperatures did not differ significantly between hutch interiors. Yet for all four compass points they were higher (4.5–6.8°C) than outside temperatures ($P < 0.0001$).

In the afternoon, temperatures in east- and north-facing hutches as well as those outside did not differ from but were lower than temperatures in south- (3–5°C; $P < 0.05$) and west-facing hutches (8–10°C; $P < 0.001$). The highest temperatures were measured in east-facing hutches in the morning hours and west-facing hutches in the afternoon. The dry bulb thermometers were positioned at calves' head height and afforded no extra shielding. This means, based on the solar incidence angle, that the thermometer sensor was either shielded by the hutch roof or exposed to the full sun. Due to the low solar incidence angle, the dry bulb thermometer was presumably exposed to the full sun in the hours of the morning. Equally, in west-facing hutches, it was exposed to the full sun in the afternoon hours, which increased the DBT values. Spain and Spiers (1996) noted a similar phenomenon and omitted values taken in sunny conditions from their air temperature (DBT) analyses. If the thermometer sensor is not shielded from solar radiation, measurements of dry bulb thermometers are considerably biased (Anderson & Baumgartner 1998). In south- and north-facing hutches, the solar incidence angle was never so low that the hutch roof would not block the thermometer from the sun. This way, shielding was provided throughout the entire measurement period. The DBT results suggest that for certain hours of the day east- and west-facing hutches provide no shade for the calf inside, either standing or lying. The same conclusion was reached as regards the BGT.

In contrast to BGT, the DBT was several degrees higher inside hutches compared to outside, for virtually all periods and in all directions of the compass. The assumption being that the heat irradiated by the hutch material warms up the air inside the hutch thereby increasing the DBT.

Spain and Spiers (1996) also found air temperatures higher inside the hutch compared to outside, in sunny conditions. They explained it as increased heating of the hutch material by solar radiation. However, the difference was only around 0.5°C. The hutch material in their study (presumably polyethylene) differed from that of ours (fibreglass-reinforced polyesther). Also, temperatures were not only taken in the hottest part of the day but also in the early morning, which could have decreased the average difference. Only a small number of studies have assessed hutch and outdoor area thermal environments separately. Manriquez *et al* (2018) looked into the effect of an aluminised film cover on the microclimate of hutches and found that within the hutch the DBT was a few degrees higher than in the outside area. Both studies were performed outdoors, and their findings are in accordance with our results. It is interesting that the two environmental measures (BGT and DBT) lead to divergent results. The conductive properties of the hutch material along with methodological detail, such as positioning and shielding of thermometers, might also contribute these contradictory findings. It is tempting to speculate that in outdoor conditions, using merely the DBT can be misleading. In hot, sunny weather calves will generally seek shade inside the hutch. However, the differences in DBT relative to location would suggest that the sunlit outdoor area provides a better, or at least similar, thermal environment than the inside of the hutch. DBT performs well in a barn environment but is less informative in outdoor conditions (Hahn *et al* 2009). Based on temperature measurements, we would conclude that since BGT and DBT measurements offer contradictory results, it would be advisable to use BGTs in outdoor studies. Herbut *et al* (2018) describe the development of heat-stress indices for use in heat stress assessment in dairy and beef cattle. Incorporating solar radiation into the indices, either directly (adjusted THI and the Comprehensive Climate Index [Mader *et al* 2006, 2010]) or in the form of the black globe temperature (the Black Globe Humidity Index [Buffington *et al* 1981], the Heat Load Index [Gaughan *et al* 2003]), makes them more suitable for outdoor housing conditions. Such indices might also be adapted for studies on calves.

Our hypothesis on compass direction influencing hutch inner microclimate was not fully confirmed. Average daily BGTs did not differ for inside hutches compared to outside which led us to conclude that the overall daily heat load of hutches was similar for all compass directions. However, periodic comparisons revealed the distribution of heat from solar radiation during the day to differ greatly between compass directions; a factor which should be taken into consideration when placing calf hutches. Despite measurements only being taken on one, single day we would not anticipate conducting further measurements over several more days leading to a different conclusion. In a previous, week-long study, we found daily patterns of behavioural measures and RR to be similar from day-to-day (Kovács *et al* 2018a,b). The chosen day was an apt representation of a typical hot, sunny day in continental Europe in which heat stress abatement measures would be necessary.

Respiratory rate

As, over time, radiant heat accumulates in the material of the hutch, time of day will influence the thermal environment and, as a direct consequence, the respiratory heat stress response of calves. Calf location was also included in

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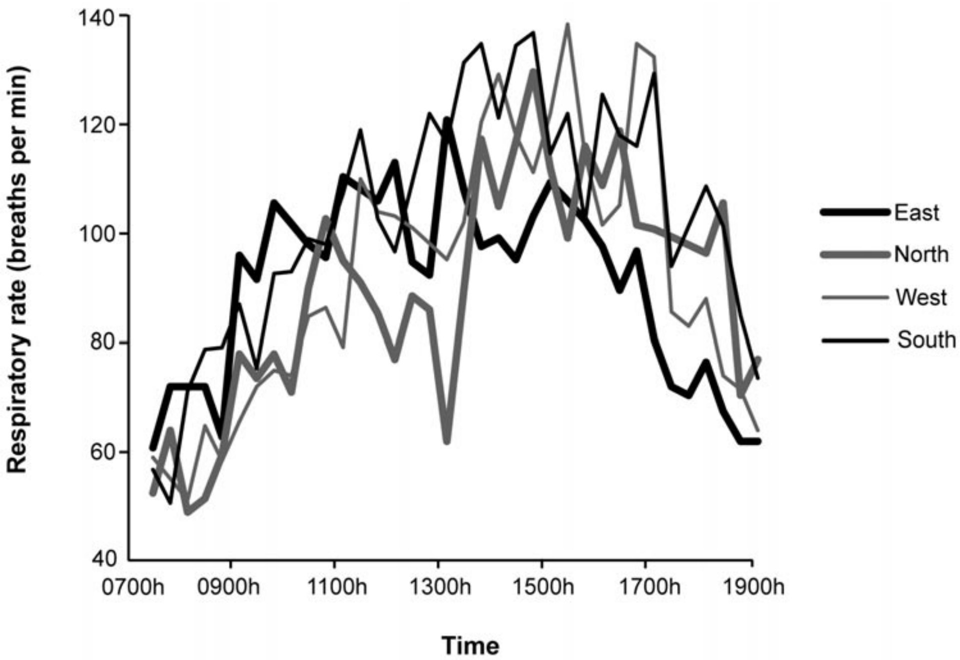
Figure 2



Mean respiratory rates of calves (n = 5 per direction) at various time-points with respect to different points of the compass.

the model as a controlling variable. The number of observations of calves located outside were relatively low — which we expected would hinder establishing statistical significance — and, on such occasions, calves were mostly in the shade. Since outdoor area temperatures were only measured in sunny conditions, we do not wish to compare the difference between inside and outside RR.

Since increased respiration is among the primary heat dissipation mechanisms, it was our assumption that changes in RR and temperatures would occur in parallel. Hence, we focused mainly on the differences in RR of hutch-located calves, comparing it to the differences found in inside temperature conditions and mean RR values measured during the observation period are shown in Figure 2.

The mean (± SD) RR for periods of the day and location of calves are shown in Table 1.

Location was found not to modify the effect of direction on RR. However, the period of the day was found to alter the differences in RR between compass directions or locations.

The daily RR average was elevated above the physiological range of 50–70 breaths per min (Piccione *et al* 2003) in all compass directions. An increased RR is evidence that calves in all hutches were being subjected to some degree of heat stress. During most of the hours of day-time, DBT was seen to be above the calves' upper critical temperature of 26°C (Spain & Spiers 1996; Collier *et al* 2019), explaining the increased RR.

Daily average RR did not differ significantly between calves housed in hutches facing different compass points, either inside the hutch or in the outdoor area. This finding mirrors those on inside BGT and DBT. We assumed that the differences in RR and temperatures would reflect a similar trend and concluded that overall heat load did not differ inside differently oriented hutches. However, throughout the day, the distribution of heat load varied with compass direction.

In the morning period (0720–1100h), average RR in east-facing hutches was 25.3 [± 8.5] breaths per min higher compared to north-facing ones ($P < 0.01$). For the same period, BGT did not show a difference between east- and north-facing hutches; however, the DBT showed a difference of 7.5 (± 1.6)°C ($P < 0.01$). No statistical significance was found for the numerical difference in RR between calves in east-facing hutches and south- or west-facing ones due, presumably, to the relatively low sample size of five calves per group.

For the midday period (1120–1500h), the RR of calves did not differ between hutches facing different points of the compass. If we assume the RR to be correlated with the level of heat load, then failure to observe any differences between compass points is in accordance with the result of temperature comparisons. Although an average 2.3°C difference was found between the highest and lowest values of inside BGT and DBT, respectively, it was not enough to induce a difference in RR.

In the afternoon period (1520–1900h), RR of calves in hutches facing west was, on average, 39.3 (± 9.7) and 40.4 (± 10.2) breaths per min higher than that of calves facing east and north, respectively. In parallel, BGT temperatures were, on average, 10.2 (± 4.4)°C and 7.1 (± 1.4)°C higher in west-facing hutches compared to those facing east and north, respectively ($P < 0.01$; $P < 0.001$). DBTs were 9.4 (± 4.6) and 8.3 (± 3.5)°C higher in west-facing hutches than in east- and north-facing hutches, respectively ($P < 0.001$).

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We concluded that the difference observed in RR could be explained by differences in the animals' thermal environment. Even the lowest measured averages were well above the RR in thermoneutrality; thus, all calves experienced some degree of heat stress.

Compass direction and period of the day had no significant influence on the association between temperature and respiration. We observed that in the measured temperature range, a 10°C increase in BGT was associated with an average 23.3 (± 0.22) increase in RR (95% CI: 1.89; 2.77; $P < 0.0001$). A rise of 10°C in DBT was associated with an average 25.3 breaths per min increase in RR (95% CI: 2.09; 2.96; $P < 0.0001$). This finding is in accordance with the differences observed in RRs between compass directions at different periods of the day.

So far, studies into methods of heat stress alleviation in dairy calves have been yet to consider the compass direction of hutches among the list of applied strategies. Our results can be compared with the effect of shading as an outdoor heat abatement measure. In the study of Kovács *et al* (2018b), net shading was associated with a 40 per min reduction in the average RR during the hottest hours of the day. Spain and Spiers (1996) observed only a 10 per min difference in the RR in the afternoon (47 vs 57 in shaded and unshaded groups, respectively) due to an artificial shading structure. However, maximal air temperatures did not exceed 38.2°C in the latter study, and temperature and RR were only measured twice a day. The magnitude of difference between the mean RR of calves inside the hutches facing different compass directions did not approach the observations of the mentioned studies. We would conclude that the overall heat stress alleviating effect of orienting hutches is negligible compared to that of shading and any advantage is only achievable in the afternoon hours. However, since newborn calves are more prone to heat stroke as a result of limited thermoregulatory capabilities and are at an increased risk of dehydration, even the slightest reduction in heat load can be crucial in the first days of life. In instances where no other heat alleviation methods are practically achievable, hutch openings should be oriented to the east or the north in summer months.

Behavioural measures

Relative frequency of behavioural measures was compared between compass points for each period of the day. Correlation within subjects was taken into account during statistical analysis. Significant differences are noted in the text to follow, along with a biological explanation and welfare implications.

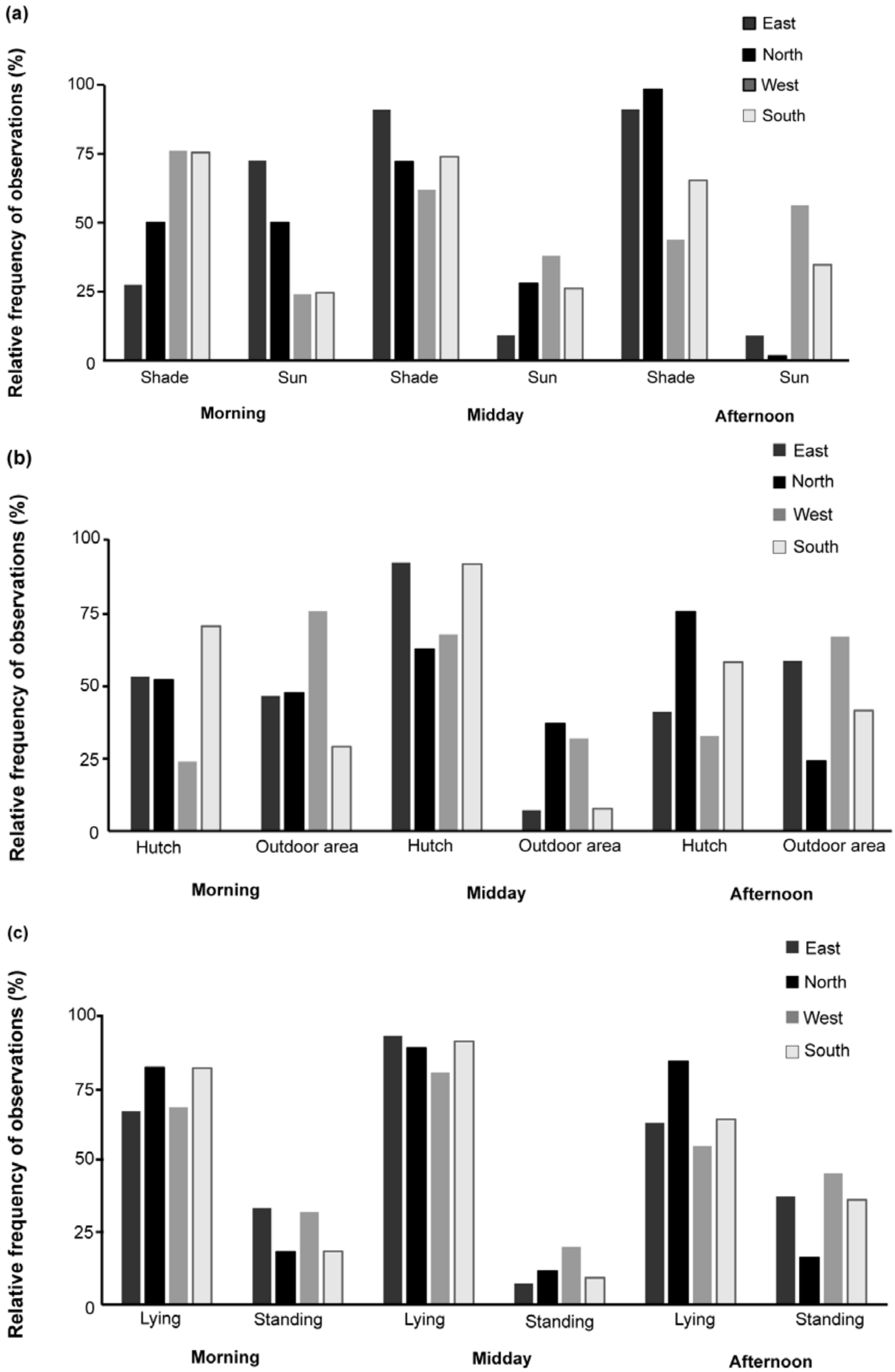
The relative frequency of observing a calf being in the sun vs shade is displayed in Figure 3. In the morning period, the probability of a calf being in shade at the time of observation (henceforth 'exposure to shade') was higher in south- (odds ratio [OR]: 11.1; 95% CI: 1.88; 59; $P = 0.03$) and west-facing (OR: 8.22; 95% CI: 1.42; 47.61; $P = 0.01$) hutches than east-facing ones. In the midday period, exposure to shade was higher inside hutches facing east than west (OR: 8.48; 95% CI: 1.41; 51; $P = 0.01$). In the afternoon period, exposure to shade was higher in east-facing hutches than south- and west-facing ones (OR: 5.8; 95% CI: 1.07; 31.46; $P < 0.05$ and OR: 16.9; 95% CI: 3.39; 85.11; $P < 0.001$, respectively). Also, exposure to shade was higher in north-facing hutches than those facing south and west (OR: 33.25; 95% CI: 1.75; 629.54; $P = 0.03$, and OR: 97.2, 95% CI: 5.36; 1763; $P < 0.001$, respectively).

Above the critical upper temperature, a shaded resting area is usually preferred over one exposed to the sun, if access is provided (Tucker *et al* 2008). Consequently, we associated greater access to shade with better welfare (Spain & Spiers 1996; Kovács *et al* 2018b). In the morning hours, shade was not available in east-facing hutches; however, the DBT did not rise above the upper critical temperature of 26°C until around 1000h. East- and north-facing hutches provided more access to shade in the hotter periods of the day than those facing the south or west. Daily changes in solar incidence angle would seemingly make this obvious however it is rarely taken into consideration when placing the calf hutches and no studies were found that assessed compass direction-induced differences in hutch microclimate. A limitation of our study was that shade preference or availability were not measured continuously. The availability of shade, for example, in terms of the shaded proportion of the calf's living space, would have been more informative.

The relative frequency of observing a calf being inside vs outside the hutch is shown in Figure 3. In the morning period, hutch preference was higher in east-facing hutches compared to west-facing ones (OR: 14; 95% CI: 1.24; 159.1; $P < 0.05$). In the midday period, it was higher in east-facing hutches than in north- (OR: 23; 95% CI: 1.34; 394.6; $P < 0.05$) and west-facing ones (OR: 23.6; 95% CI: 1.46; 381.4; $P < 0.05$), respectively. No differences were found in the relative frequency of hutch preference for different compass points in the afternoon period.

We assumed access to shade to be the main priority in influencing preference for the hutch or the outdoor area for calves. In the midday period, both shade access and hutch preference were higher in east- compared to west-facing hutches, which partially confirms our hypothesis. However, access to shade is not the only determining factor in choosing a place to rest. Were shade to be unavailable or both hutch and outdoor area shaded, then other factors would also come into play. Calves tend to seek a microenvironment within or outside the hutch that best suits their comfort and well-being. Their selection depends on outdoor temperature and time of day (Brunsvold *et al* 1985). Hutch or outdoor preference could not be linked directly to a single one (or two) of the climatic parameters. It is influenced by a combination of all the factors affecting heat transfer. We concluded that the 'operative temperature', ie the temperature as perceived by the animal, could be the appropriate measure determining location preference. It integrates mean radiant temperature (incorporating the amount of solar radiation), wind speed, humidity and hair coat characteristics. Operative temperature is used mainly in human studies, for example, in the assessment of thermal comfort in workplaces. However, when used correctly, it

Figure 3



Relative frequency of (a) being in the sun vs shade, (b) location preference (hutch vs outdoor area) and (c) body posture (lying vs standing) at the time of observation among calves housed in hutches facing different points of the compass. Animals were observed every 20 min in morning (0720–1100h), midday (1120–1500h) and afternoon (1520–1900h) periods.

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also reliably models the relationship between an animal's thermal environment and its physiology (Dzialowski 2005).

The relative frequency of observing a calf lying vs standing is displayed in Figure 3. Lying prevalence did not differ between compass points in the morning and midday periods. It was higher in north- compared to west-facing hutches in the afternoon period (OR: 4.38; 95% CI: 1.32; 14.58; $P < 0.01$).

Observing body posture at distinct time-points — even as frequently as every 20 min — does not hold as much information as continuous monitoring (Kovács *et al* 2018a). In the study of Kovács *et al* (2018a) a 75–80% higher frequency of lying down was observed in shaded vs unshaded calves. We assumed that if the difference in comfort level between east- or north- and south- or west-facing hutches had approached the difference that occurred between sunny and shaded conditions, it could have been detected with the obtained sampling frequency. The significant difference between north- and west-facing hutches in the afternoon period suggests that directing hutch entrance to the north confers some advantages. However, it also means that merely altering the compass direction of the hutch entrance cannot reduce the heat load to the extent of that of shading (Spain & Spiers 1996; Kovács *et al* 2018b).

Animal welfare implications

Hutch-reared dairy calves have been shown to experience a drastically high heat load in the summer months. Directing their hutch entrances to face the east or the north offers a slightly more favourable microclimate than facing south or west. However, any advantage is not comparable to the heat alleviating effect of, for example, shading. In terms of welfare, our results highlight that it is crucial to use methods that reliably assess solar radiation when describing the thermal environment of livestock reared outdoors.

Conclusion

In outdoor studies, indices incorporating the BGT picture the animals' thermal environment better than the DBT. Based on the environmental- and animal-based parameters, we concluded that the positioning of hutch entrance towards east or north in summer has some advantages. However, the differences in heat load between the most and least favourable microclimates are so low that hutch positioning may address only some of the effects of acute heat stress.

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