Thermoregulatory Responses Associated with Lying and Standing in Heat-Stressed Dairy Cows

P. E. Hillman, C. N. Lee, S. T. Willard

Abstract. *The purpose of this study is to characterize the thermoregulatory responses of unrestrained heat-stressed dairy cows within a freestall environment using fan and spray configurations for cooling cows while lying or standing. An experimental treatment sprayed individual cows lying in freestalls from 11:00 to 15:00 (stall cooling period) during hot-humid weather (average THI of 82.4) over a five-day trial period, using ultrasound transceivers to detect their presence. Core body temperatures were continuously monitored with vaginal temperature loggers. To assess behavioral responses, cows were visually monitored during the stall cooling period. Respiration rates and dorsal surface temperatures were recorded when the cow lay down or stood up in a stall. Core body temperature of lying cows rises at a rate of 0.6°C h^{-1} when exposed to fan cooling alone. Adding spray cooling to fan cooling slows the rate of rise to 0.3°C h^{-1}. With or without freestall spray cooling, cows stand and seek cooling when their core body temperatures reach 38.9°C. Core body temperature is a more reliable indicator than either dorsal skin temperatures or respiration rates for predicting when cows stand and seek cooling. Core body temperatures of cows fall at a rate of 0.7°C h^{-1} while standing under feed line spray and fan cooling, while core body temperatures of cows standing under fans without spray remain unchanged. To cool heat-stressed cows, water spray is required in addition to fans while the cows are standing. Fans alone are inadequate.*

Keywords. *Body temperature, Cows, Dairy, Evaporative cooling, Freestall, Heat stress, Lying, Respiration rates, Standing, Thermoregulation.*

Keeping cows comfortable and productive remains a challenge to dairy farmers during hot summer months. Cows must dissipate considerable heat as a byproduct of milk production, which can equal the heat loss due to maintenance (National Research Council, 1989). This helps explain why they are heat stressed at a THI of only 72 (Armstrong, 1994). Unfortunately, keeping a barn below a THI of 72 requires expensive air conditioning (Bray et al., 2003). A more economical solution is to cool cows using spray or misting when the barn's THI exceeds 72. Spray alone cools cows (Igono et al., 1985; Hillman et al., 2001; Brouk et al., 2003; Bray et al., 1994) and improves milk production (Igono et al., 1985). Direct wetting of the skin is more effective than cooling the air for improved milk production (Frazzi et al., 2002). Using fans alone also cools cows (Spain and Spiers, 1998; Hillman et al., 2001; Frazzi et al., 2000; Brouk et al., 2003), but spray is more effective than fans (Brouk et al., 2003). The combination of both wetting and fans is the most effective method for cooling cows (Hillman et al., 2001; Frazzi et al., 2000; Brouk et al., 2003), and this combination reduces milk production losses (Igono et al., 1987; Strickland et al., 1989; Bucklin et al., 1991; Lin et al., 1998; Meyer et al., 2002; Turner et al., 1992). It is not surprising that spray and fan cooling is frequently used in commercial freestall dairies in the western U.S. (Armstrong et al., 1999). Although spray and fans effectively cool cows, we know of no studies that track the effectiveness of spray and fans on the thermoregulatory responses of unrestrained cows in a freestall facility.

Normally cows spend 11 to 12 hours a day lying in freestalls (Friend and Polan, 1974; Perera et al., 1986). Cows spend less time lying and more time standing when heat stressed (Hayasaka and Yamagishi, 1990; Frazzi et al., 2000; Overton et al., 2002; Perera et al., 1986; Shultz, 1984). Standing has the thermal heat loss advantage over lying because more surface area is available for evaporation (Igono et al., 1987). Spending more time standing without eating is also an indicator of poor stall comfort (Haley et al., 2001). We can assume that a lying, heat-stressed cow is uncomfortable even when lying on ideal bedding.

The first objective of this study was to determine the impact of adding spray cooling to different areas of a fan-cooled freestall dairy barn on various thermoregulatory parameters (core body temperature, respiration rate, and dorsal skin temperature). The second objective was to determine if core body temperature, dorsal skin temperature, or respiration rate is a reliable thermoregulatory indicator when a cow stands up to seek cooling.

Materials and Methods

Animals

Twenty Holstein cows were equally divided into two groups with similar days in milk and milk production. The

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groups are referred to as the control group (with no stall spray cooling) and the experimental group (with stall spray cooling). On the third day, one of the cows in the experimental group became lame and was replaced by an alternate. Thus, 21 cows were used in this study. Seven were primiparous, and 14 were multiparious. At the beginning of the trial, the average days in milk for all cows was 286 ±24 (mean ±SE) with an average production of 29.5 ±1.2 kg milk cow^{-1} day^{-1} (mean ±SE; all results are reported as mean ±SE unless stated otherwise). All cows but one were pregnant. Cows were milked twice daily at 3:30 and 15:30.

Facilities

This experiment was conducted from 19 to 23 August 2002 (hereafter referred to as the "trial period") at the Mississippi State University Dairy Research Center in Starkville, Mississippi. Half of a four-row freestall barn with a center drive-through feed alley was utilized for this study. The barn is 39 m long and oriented east-west with open sides, 3.6 m eave height, and an insulated roof with a second roof cap over the drive-through with 0.6 m openings on either side. The two groups of cows in this study were placed in separate pens on the south side of the barn. This half of the barn has 52 head-to-head stalls equally divided into 26 stalls by a crossover with 13 stalls facing the feed alley and 13 stalls facing a freestall alley. For each group of cows, ten stalls facing the feed alley were left open, while the remaining 16 stalls were blocked off. The crossover was left open for access to water troughs on the outside of the freestall alley. The stalls are 1.23 m wide by 2.13 m long and bedded with sand held in place with tires.

Fan and Spray Cooling Common to the Control and Experimental Groups

Two fans were placed over the freestalls perpendicular to five stalls each, and one fan was placed at the end of the feed line for both groups of cows. The bottom of the fans was 3 m above the freestalls and 2.4 m above the feed line for each group pen. Six evenly spaced feed line sprayers with a flow of 2 L min^{-1} were set 2 m high, providing large-droplet, low-pressure (340 kPa) wetting of the skin. Both fans and feed line sprayers were on continuously 24 h day^{-1}. The fans were 0.5 HP and 92 cm in diameter (model VS36, Schaefer Ventilation Equipment, Sauk Rapids, Minn.).

Stall Spray Cooling for Stall-Cooled Cows

Stall spray cooling was provided from 11:00 to 15:00 (hereafter referred to as the "stall cooling period"), when the highest daily THI values were expected to occur (figs. 2 and 3), and was turned off when the cows were moved to the milking parlor for PM milking (fig. 3). Individual cows in the experimental pen were sprayed with water when detected with an ultrasonic transceiver when lying down (Hillman and Lee, 2002; Hillman et al., 2000). They were sprayed with about 160 mL water (over a time of about 5 s) on their backs (coverage about 0.2 m^2) every 3.2 min. This amount was deemed enough to wet the hair coat with minimal runoff. The spray pattern was aimed at the center of the stall, so some overspray with runoff occurred when the cow was lying to the left or right of the stall. Occasionally, the sensor did not trigger (<5% of occurrences) when a cow was present.

Experimental Procedure

Visual observations of behavior were recorded during the stall cooling period (from 13:20 to 15:00 on 19 August, and from 11:00 to 15:00 on 20 to 23 August). One observer was assigned to the control group and another observer to the experimental group. Observers rotated daily from group to group. The following activities were recorded: time of day when a cow lay down, stood up, stood away from the feed line, and stood at the feed line. Standing and lying times were only recorded when the cow's behavior was undisturbed by people. Respiration rates were measured by recording the time for 20 flank movements when the cow lay down and when the cow stood up.

Dorsal skin temperatures were monitored with two models of handheld IR thermometers (models Raynger ST and PM Plus, Raytek, Santa Cruz, Cal.) when a cow stood up or lay down. Both thermometers had resolutions of 0.1°C and were calibrated to a standard black body (the inside of a copper sheet metal box, painted with ultra-flat black paint, and submerged in a temperature-controlled water bath) to give an accuracy of ±0.5°C.

Vaginal temperatures (T_{vagina}) were monitored every 5 min with a commercial waterproof temperature logger (model HOBO Water Temp Pro, Onset Computer Corporation, Bourne, Mass.) encased in a specially constructed, soft plastic anchor with eight fingerlike projections to keep it from being discharged from the vagina (Hillman et al., 2003). For 118 measurements with 20 loggers, the loggers measured 0.06 ±0.01°C (mean difference ±SE for paired *t*-test, t = 4.22) lower than rectal (Hillman et al., 2003). The loggers have a resolution of 0.05°C, and the rectal probe (model GLA M525/550, GLA Agricultural Products, San Luis Obispo, Cal.) has a resolution of 0.1°C. Both were calibrated to a National Institute of Standards and Technology traceable thermometer to give an accuracy of ±0.2°C within the range 37°C to 41°C.

An example of changes in vaginal temperature during the stall cooling period is illustrated in figure 1, where duration of lying and standing is recorded. The rate of change in T_{vagina} was determined for each activity when enough data points clearly formed a straight line. The slope of the line was determined using Microsoft Excel's trendline feature for a linear regression. The rates of vaginal temperature change for a change in activity is relatively linear. Body weights and body condition scores were taken before and after the experimental trial, as were the following milk parameters: percent fat, percent protein, somatic cell counts, and lactose. Milk production was recorded at each milking. Air temperature and relative humidity within the barn were recorded (HOBO Pro RH/Temp Data Logger, Onset Computer Corporation, Bourne, Mass.) every 5 min throughout the trial.

Results and Discussion

Throughout the trial period, THI values during the stall cooling period were fairly consistent (fig. 2), with an average dry bulb temperature of 31.5°C, a relative humidity of 61.1%, and a THI of 82.4. These values are within the "danger" (i.e., THI 79 to 83) range for livestock weather safety (Hahn, 1999). Averaging all 5 min environmental measurements over the five-day trial period, the dry bulb temperature was 27.3 ±0.11°C, relative humidity was

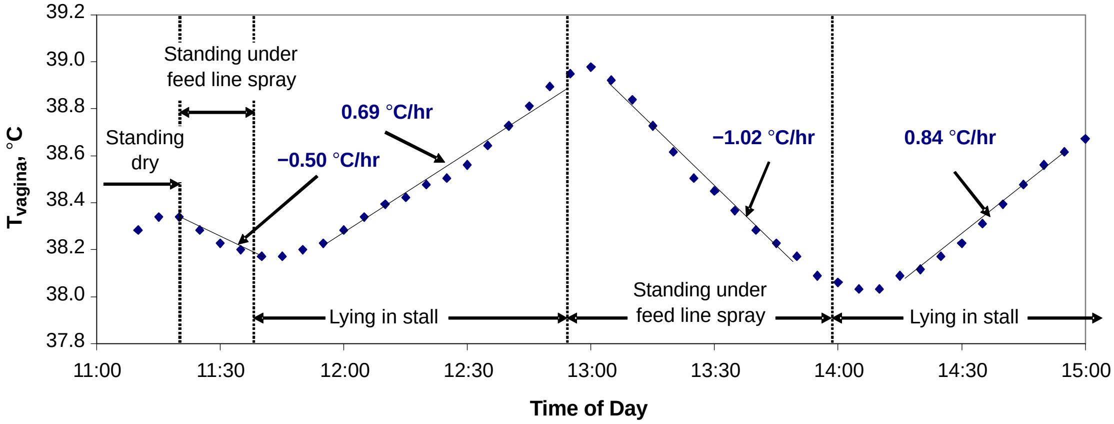

Figure 1. Example of the activities and T_{vagina} of cow during the stall cooling period to illustrate the recording and interpretation of data. In this example, cow 9303 (a member of the control group) was observed on 20 August 2002, and the durations of individual activities were recorded: 17 min standing under the feed line spray and fans, 77 min lying in the stall with fans only, and 64 min standing in the feed line with spray and fans. The duration of the final lying activity was not determined because the cow was still lying at the end of observation period.

77.1 ±0.40%, and the THI was 78.0 ±0.12. The coolest air temperatures (averaged 23.2 ±0.06°C) occurred between 01:00 and 07:00. Average air speed at cow height of a lying cow was 1.3 ±0.13 m s^{-1} for the experimental pen stalls and 1.4 ±0.10 m s^{-1} for the control pen stalls. Air speed at standing cow height at the feed line was highest nearest to the fan (4.7 m s^{-1}) and lowest at the far end of the feed line (0.8 m s^{-1}), with an overall average of 2.0 ±0.23 m s^{-1} for both the control and experiment pens.

Body weights dropped 16.9 ±5.1 kg for the control cows and 21.7 ±4.7 kg for the experimental cows from the morning of 19 August until late afternoon of 23 August (table 1). Although both drops were significant ($P < 0.01$), the differences between control cows and experimental cows were not significant. No changes were observed in milk production or milk quality during the trial period or between the experimental and control cows. These results are consistent with a five-day experiment by Brouček et al. (1998) where milk yield or milk composition did not change when daily temperatures oscillated from 23°C to 34°C.

During the stall cooling period no difference in T_{vagina} was observed (fig. 3). Average T_{vagina} for the control group was 38.56 ±0.01°C, and average T_{vagina} for the experimental group was 38.57 ±0.01°C (NS). During the non-cooling period (15:00 to 11:00), T_{vagina} of the experimental group was 0.22 ±0.01°C higher than T_{vagina} of the control group ($P < 0.01$). No behavioral observations were collected to explain this difference during the non-cooling period. It is important to note that the cows had higher T_{vagina} temperatures outside the stall cooling period when air temperatures were cooler than during the stall cooling period. Vaginal temperatures increased following both AM and PM milking, which could be a result of increased metabolic heat production due to increased physical activity of walking to

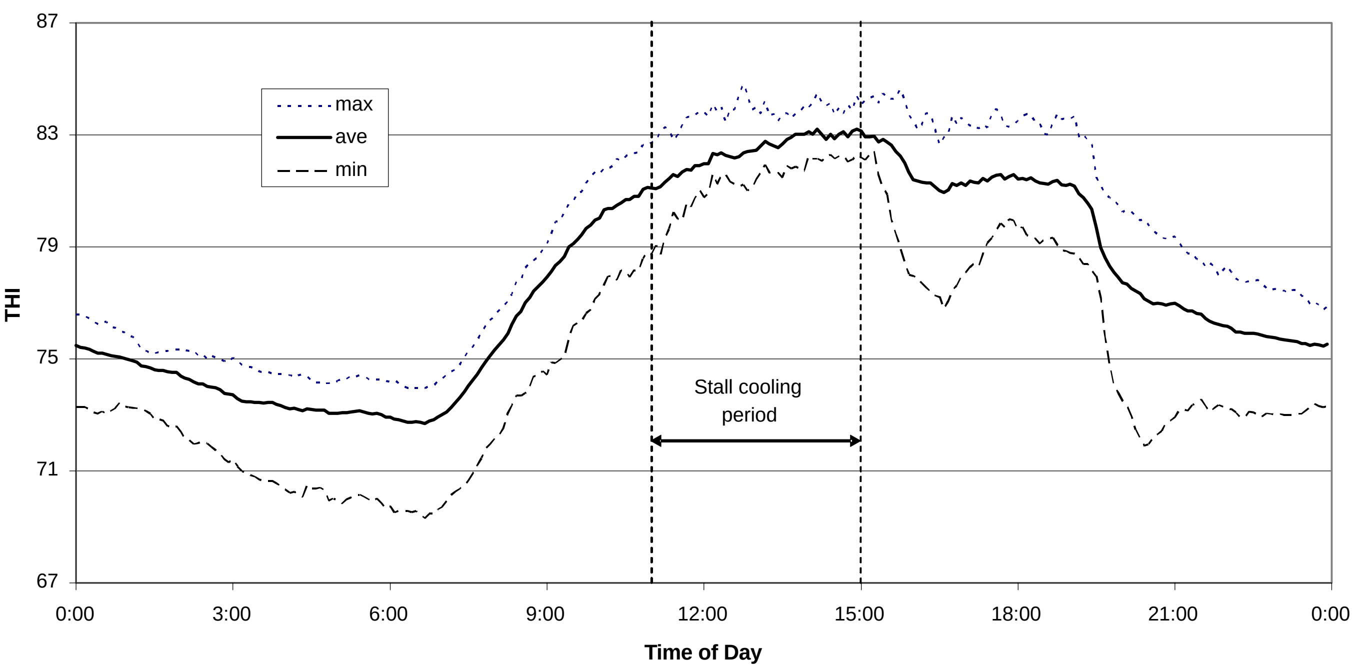

Figure 2. THI values over the trial period (19 to 23 August 2002). During the stall cooling period (11:00 to 15:00, except on 19 August which began at 13:20), the stall spray system in the experimental pen was turned on and behavioral observations were recorded.

Table 1. Body weights, milk production and milk quality, mean ±SE (*n*).

	Control Group	Experimental Group	P-value
Body weight			
First day of trial (kg)	665 ±31.6 (9)	686 ±35.0 (7)	0.653
Last day of trial (kg)	648 ±31.4 (9)	665 ±37.9 (7)	0.738
Weight loss during trial (kg)	16.9 ±5.1 (9)[a]	21.7 ±4.7 (7)[a]	0.751
Milk production			
First day of trial (kg day^{-1})	29.99 ±1.9 (9)	29.04 ±1.5 (9)	0.705
Average during trial (kg day^{-1})	29.11 ±1.9 (9)	28.96 ±2.1 (9)	0.956
Last day of trial (kg day^{-1})	28.14 ±2.1 (9)	28.74 ±2.1 (9)	0.843
Energy-corrected milk production			
First day of trial (kg day^{-1})	29.13 ±2.0 (9)	28.51 ±1.8 (9)	0.817
Last day of trial (kg day^{-1})	30.86 ±2.0 (9)	32.09 ±2.2 (9)	0.669
Fat			
One day prior to start of trial (%)	3.71 ±0.17 (10)	3.94 ±0.27 (9)	0.476
Last day of trial (%)	3.66 ±0.11 (10)	4.29 ±0.34 (9)	0.115
Protein			
One day prior to start of trial (%)	3.22 ±0.07 (10)	3.27 ±0.15 (9)	0.789
Last day of trial (%)	3.15 ±0.09 (10)	3.45 ±0.30 (9)	0.362
Lactose			
One day prior to start of trial (%)	4.96 ±0.11 (10)	4.92 ±0.12 (9)	0.824
Last day of trial (%)	4.95 ±0.09 (10)	4.65 ±0.19 (9)	0.179
Somatic cell count			
One day prior to start of trial (thousands)	224 ±87 (10)	122 ±55 (9)	0.340
Last day of trial (thousands)	474 ±232 (10)	167 ±70 (9)	0.234

[a] Weight losses within each treatment group are significant at the 0.01 probability level.

the parlor or increased hormone levels. The cows were also placed in environments with fewer opportunities for cooling. Although the cows were spray cooled in the holding pen, not all cows were uniformly sprayed and they were crowded together, reducing skin surface for cooling. No cooling was available in the milking parlor. Vaginal temperatures did not begin to fall for 2 to 3 h after milking, even though the cows had returned to the freestall barn. These data emphasize the importance of looking at heat stress for the entire day, not just the period of highest THI, which occurred in the afternoon.

Many freestall barns are equipped with cooling in the form of spray, fans, or both because THI values commonly exceed the threshold of 72 for heat stress in high-producing dairy cows in the summer (Armstrong et al., 1999). Cooling is presumed to offer a microclimate for thermal relief during periods of high THI values. In this study, the effectiveness of

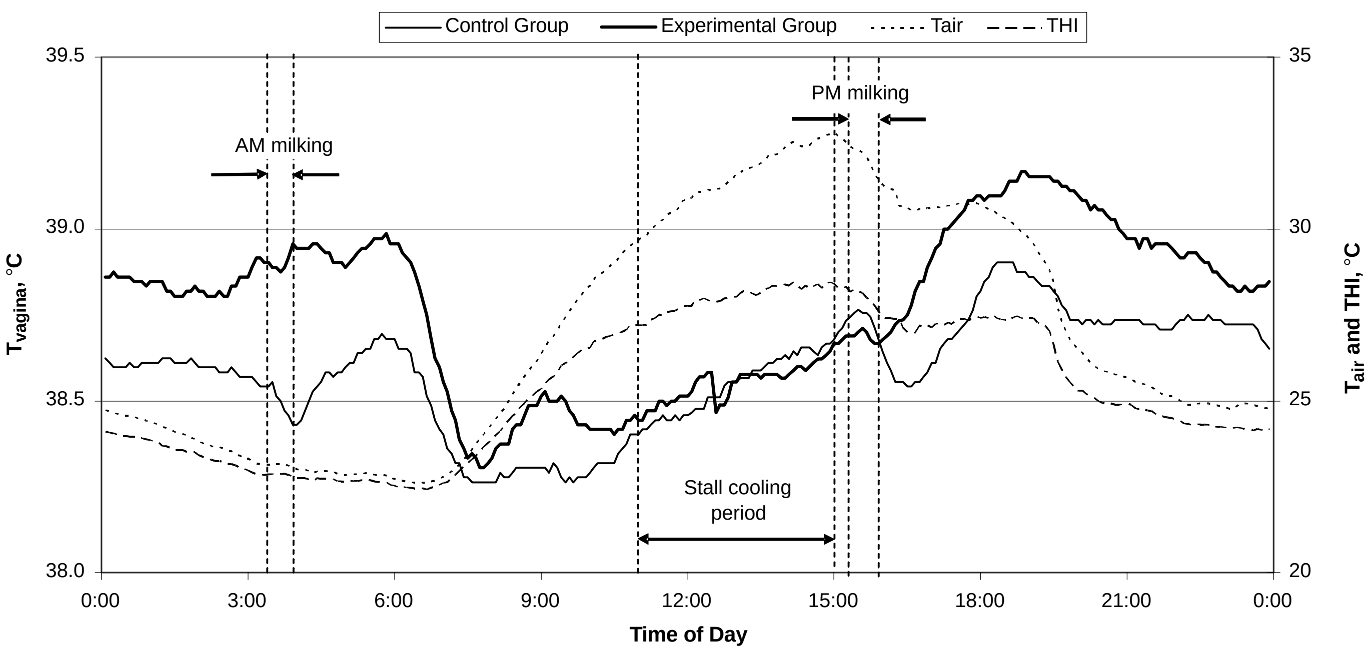

Figure 3. Average air temperatures and THI (scaled to °C) in the freestall barn and vaginal temperatures of the ten cows in the control pen and the ten cows in the experimental pen averaged over the five-day trial period. Ambient temperatures in the holding pen and the milking parlor were not recorded.

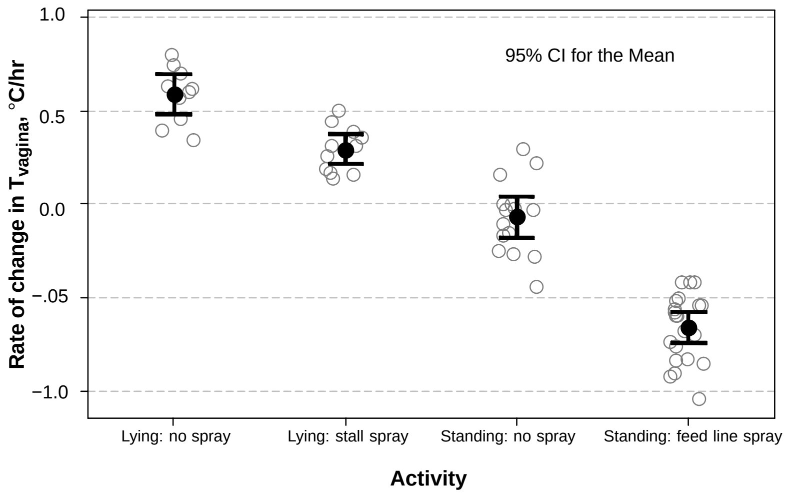

Figure 4. Rates of change of T_{vagina} of cows in the control group with fans and no stall spray, in the experimental group with fans and stall spray, and with the control and experimental groups combined for standing with fans only or with fans and feed line spray. Each circle represents the average of all observations for an individual cow. All four groupings differ from each other at the <0.001 probability level. A positive rate of change rate indicates that the cow's core body temperature is rising, and a negative rate of change indicates that the cow's core body temperature is falling. The data points are spread out in the *x*-direction to make them more visible.

spray cooling systems was monitored by how quickly the core body temperature of the cows rose or fell. The rate of core body temperature change was compared in four distinct areas within the freestall barn where behavior (lying vs. standing) helps define the location with respect to height: (1) lying in a freestall with fan cooling only, (2) lying in a freestall with fan and spray cooling, (3) standing in the feed line with fan and spray cooling, and (4) standing with no spray (fig. 4). Standing with no spray includes standing in the freestall with fans, standing in the feed alley outside the range of spray but within the range of the fans, or standing in the freestall alley without fans or spray where water troughs were located. The data for all three locations for standing with no spray are grouped together because of the paucity of observations in each location. Vaginal temperatures of cows lying in freestalls cooled only by fans rose (0.59 ±0.05°C h^{-1}) at a faster rate than that of cows cooled with both spray and fans (0.29 ±0.04°C h^{-1}). Vaginal temperatures of cows fell by 0.59 ±0.04°C h^{-1} to 0.75 ±0.06°C h^{-1} when standing in the feed line exposed to both fans and spray. For cows standing without spray, vaginal temperatures did not rise or fall (fig. 4 and table 2). These data emphasize the benefit of spray cooling with fans compared to fans alone to keep cows cool.

Three significant responses ($P < 0.05$) between the experimental group and the control group cannot be explained. In the first of these unexplained responses, the control group stood twice as long with no spray as the experimental group (table 2). We did not have enough observations to help explain this difference, especially when the cows standing with no spray included three different behaviors, as previously noted. The second unexplained response was that the T_{vagina} of the control cows, while standing under feed line spray, dropped at a faster rate than that of the experimental cows (table 2), which is a corollary of the third unexplained response where the control cows spent less time standing under the spray than the experimental cows (table 2). Several factors could affect these last two responses, such as differences in behavioral selection of the feed line spray for optimal cooling. Further studies would be required to explain these explained responses, although the importance between these responses is not critical to our understanding of heat stress behavior of dairy cows within freestall barns.

Heat-stressed cows in this study have two conflicting behaviors. They must stand under fans and spray to cool when they would normally spend more time lying. In this study, the cows oscillated between these two behaviors during the stall cooling period and were able to maintain their vaginal temperatures at 38.6°C when exposed to high THI values of 82.4. This suggests that the available feed line spray and fans were sufficient in alleviating heat stress. Adding spray cooling, while lying, increased the lying time by half an hour (table 2).

Table 2. Rate of change of vagina temperature and duration of activity of cows with access to stalls with and without spray cooling, mean ±SE (*n*). Each sample (*n*) represents the average of all observations for an individual cow.

Activity	Control Group	Experimental Group	P-value
Lying			
Δ T_{vagina} (°C h^{-1})	0.59 ±0.05 (10)	0.29 ±0.04 (11)	0.000
Average time per lying event (min)	72.8 ±3.8 (10)	101.7 ±5.8 (11)	0.001
Standing with no spray			
Δ T_{vagina} (°C h^{-1})	0.00 ±0.07 (6)	−0.12 ±0.07 (9)	0.261
Average time per standing event (min)	53.0 ±8.3 (5)	24.1 ±4.2 (9)	0.021
Standing under feed line spray			
Δ T_{vagina} (°C h^{-1})	−0.75 ±0.06 (10)	−0.59 ±0.04 (11)	0.039
Average time per standing event (min)	41.0 ±3.6 (10)	62.5 ±9.1 (11)	0.048

Table 3. Thermoregulatory responses upon lying down and standing up in the stall with and without spray cooling during the stall cooling period over the five-day trial period, mean ±SE (*n*). Each sample (*n*) represents the average of all observations for an individual cow. Standing and lying times were only recorded when the cow was undisturbed.

Thermoregulatory Response	Control Group	Experimental Group	P-value
Vaginal temperature (T_{vagina})			
On standing up (°C)	38.95 ±0.04 (10)	38.86 ±0.09 (11)	0.372
On lying down (°C)	38.31 ±0.06 (10)	38.37 ±0.08 (11)	0.573
Respiration rate			
On standing up (breaths min^{-1})	90.6 ±3.6 (10)	73.5 ±4.3 (11)	0.007
On lying down (breaths min^{-1})	61.8 ±2.3 (10)	56.1 ±1.4 (11)	0.052
Dorsal surface temperature			
On standing up (°C)	35.51 ±0.15 (10)	34.64 ±0.26 (11)	0.011
On lying down (°C)	33.89 ±0.22 (10)	33.53 ±0.30 (11)	0.339

This study offered a unique opportunity to determine whether core body temperature, respiration rate or dorsal skin temperature is the best indicator for standing behavior when heat-stressed cows seek cooling. Comparing spray cooling on one group of lying cows to another group without spray provided a method of altering the duration of lying, respiration rate, dorsal skin temperature, and core body temperatures between the two groups. A physiological parameter that triggers cooling behavior would be expected to be repeatable with little variation. In this study, core body temperature displayed such behavior upon reaching 38.9±0.05°C. It did so regardless of the greater variation in the duration of lying, dorsal skin temperature, and respiration rates (tables 2 and 3). This is expected because the thermoregulatory system attempts to maintain deep body temperature about a setpoint. Although this study cannot establish that a core body temperature of 38.9°C is the determinant threshold for cool-seeking behavior, it does support this hypothesis. In a practical sense, using a core body temperature of 38.9°C as the threshold reference for heat stress is a more accurate benchmark for dairy farmers or researchers than less predicable physiological responses such as respiration rate or dorsal skin temperature, although they are easier to measure.

Conclusions

Thermal behavior of heat-stressed lactating Holstein cows housed in a freestall barn was observed during early afternoon over a five-day period where THI averaged 82.4. Thermoregulatory responses were compared in four distinct areas of the freestall barn where core body temperature increased, decreased, or remained the same. Core body temperature rose for cows lying in freestalls, where the rate of temperature rise was less under spray and fan cooling (0.29 ±0.04°C h^{-1}) than under fan cooling alone (0.59 ±0.05°C h^{-1}). Lying time under spray and fans (101.7 ±5.8 min) was about 40% longer than under fans alone (72.8 ±3.8 min). When cows were standing under both spray and fans, core body temperature fell at a rate of 0.67 ±0.04°C h^{-1}. Core body temperature remained about the same (−0.07 ±0.05°C h^{-1}) when standing without spray. With or without spray, cows stood when their core body temperature reached 38.90 ±0.05°C. On standing, sprayed cows had lower dorsal surface temperatures (34.6 ±0.3°C) and lower respiration rates (73.5 ±4.3 breaths min^{-1}) than cows without spray (35.5 ±0.2°C and 90.6 ±3.6 breaths min^{-1}, respectively). Core body temperature is a more reliable indicator than dorsal surface temperature or respiration rate when a cow stands from lying in a freestall during hot weather, suggesting that core body temperature is the physiological stimulus that initiates standing in order to seek cooling. The cows lay down when their core body temperature was 38.33 ± 0.05°C, dorsal skin temperature was 33.7 ±0.2°C, and respiration rate was 58.8 ±1.4 breaths min^{-1}.

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