The effect of day-only versus day-plus-night cooling of dairy cows

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ABSTRACT

The aim of this study was to assess effects on milk yield (MY), rumen temperature, and panting score when lactating dairy cows were cooled during the day only or during the day and night. The study was conducted over 106 d during using 120 multiparous Holstein-Friesian cows assigned to 2 treatments (60 cows/treatment; 2 pens/treatment): (1) day cooling (DC): overhead sprinklers (large droplet) and fans while in the dairy holding yard only, shade and fans at the feedpad, and a shaded loafing area; and (2) enhanced day+night cooling (EDN): overhead sprinklers (large droplet) and fans in dairy holding yard, ducted air blowing onto cows during milking, plus thorough wetting (shower array) on exit from dairy; shade and fans at feedpad (turned off at night); and shaded loafing area + ducted fan-forced air blowing onto cows at night. The ducted air at night was manually activated at 2030 h when the maximum daily temperature-humidity index exceeded 75 and remained on until 0430 h the next day. The cows were fed a total mixed ration ad libitum, and feed intake was determined on a pen basis. Rumen temperature and cow activity were obtained from each cow at 10-min intervals via rumen boluses. Panting scores were obtained by direct observation 4 times a day at approximately 0430, 0930, 1530, and 2030 h. The cows were milked twice daily: 0500 to 0600 h and 1600 to 1700 h. Individual MY were obtained at each milking and combined to give individual daily totals. The EDN cows had greater daily MY (+2.05 kg/cow per day) over the duration of the study compared with DC cows. Rumen temperature during the third heat wave was lower for EDN (39.58 ± 0.01°C) than for DC (40.10 ± 0.01°C) cows.

Key words: cooling, night time, thermal comfort, performance

INTRODUCTION

Thermal stress is a major limiting factor in dairy production in tropical, sub-tropical, and temperate climates during summer (Berman, 2008), and it has been identified as a significant risk to the sustainability of global dairy production (Hennessy, 2007). The major and most obvious contribution to productivity loss in dairy cattle from heat stress is decreased feed intake and subsequent reduced milk yield and milk quality. The effect of heat stress on feed intake does not fully explain the reduction in milk yield. It should be noted that heat stress results in reductions in milk yield that are greater than the impact of reduced feed intake on its own (Wheelock et al., 2010; Baumgard et al., 2011). Less obvious effects are decreased reproductive performance and increased prevalence of animal health problems (Wheelock et al., 2010). Evaporative cooling is the main means by which dairy cows can reduce heat load. Evaporative cooling is achieved via sweating, panting, or evaporation of water from the coat of the cow (Berman, 2008). Evaporative cooling is affected by wind speed, dry bulb temperature, relative humidity, and the physical properties of the cow’s hair coat (Gebremedhin et al., 2008). Cooling infrastructure, whether by the use of shade, fans, sprinklers, or a combination of all of these, comes at a cost, and therefore it is essential that cooling strategies are cost effective (Davison et al., 2016). Moreover, cooling strategies may be more effective where they are applied to maximize the animal’s natural capacity to dissipate heat.

Heat dissipation from the animal is enhanced when there is a negative temperature gradient between the animal and the environment (i.e., when the environmental temperature is lower). During periods of high heat load, the temperature gradient is often small or positive (i.e., animals gain heat from the environment), so strategies to reduce heat load such as artificial cooling...
and nutritional interventions are used. Logically, dairy cows should be able to dissipate body heat better at night (when ambient temperature is lower) than during the day (Scott et al., 1983). Igono et al. (1987) reported that regaining normal body temperature overnight was a critical factor in maintaining milk production during periods of heat stress. Beef feedlot studies have suggested that nighttime heat load reduction is required if beef cattle are to cope with high daytime heat loads (Mader, 2003; Gaughan et al., 2008a). Cooling cattle at peak ambient temperature has been reached and continuing that cooling into the early evening and early morning appears to be beneficial by lowering mean rectal temperature and respiration rate and maintaining DMI compared with cattle only cooled during the day (Spiers et al., 2001). During heat waves, the minimum nighttime temperature may not allow cows to dissipate sufficient heat to enable body temperature to return to normal for a sufficient period to ensure ongoing normal physiological function. This can be further exacerbated where relative humidity is high at night and there is little to no airflow. Overall, this failure to dissipate heat can result in a progressive increase in body heat load. Nighttime cooling strategies must be in addition to heat alleviation during the hottest part of the day to ensure animal well-being is maintained (Gaughan et al., 2008a).

In dairies, heat load is usually managed during the hottest parts of the day by the use of shade, fans, sprinklers, or various combinations of these (West, 2003; Chen et al., 2015); however, there is an increasing trend to have fans and other cooling strategies running 24 h/d. It is well known that the application of water (in association with adequate air flow) will reduce body temperature and respiration rates, and will minimize reductions in feed intake and milk yield during periods of hot weather (Flamenbaum et al., 1986; Means et al., 1992; Chen et al., 2013, 2015). The use of fans and the application of water can be costly, especially if utilized over long periods each day. In many instances, shade is the most economical option for reducing heat load. Shade will reduce the impact of solar load (Bond et al., 1967; Curtis, 1983), but has little effect on air temperature, and does nothing to enhance heat loss at night. It should be noted that shade structures may reduce the radiant heat load from cows at night because they reduce radiant heat loss from the cows to the cooler night sky.

Much of the published work regarding cooling strategies for dairy cows has focused on cows housed in barns or feedlots. Relatively few studies (e.g., Valtorta and Gallardo, 2004; Tucker et al., 2008; Schütz et al., 2014; Davison et al., 2016; Veissier et al., 2018) have investigated cooling options for cows that are largely pasture based or managed on a feedpad. The current study is focused on cows housed on a feedpad.

The aim of this study was to determine the effects of adding nighttime cooling in addition to daytime cooling on milk yield, rumen temperature, and well-being of early lactation cows exposed to natural high heat load.

**MATERIALS AND METHODS**

This study was conducted with the approval of The University of Queensland (UQ) animal ethics committee (SAFS/473/17), in accordance with the guidelines described by the Australian National Health and Medical Research Council (2013) and Queensland Department of Agriculture and Fisheries (2009).

One hundred twenty Holstein-Friesian dairy cows due to calve from mid-January to mid-March were blocked by parity and previous lactation milk yield (MY); then, similar pairs of cattle were randomly assigned to 1 of 2 treatment groups. The study was undertaken at the UQ Research and Training Dairy located on the UQ Gatton Campus, in southeast Queensland, Australia (27.54°S, 152.34°E; 90 m above mean sea level). The site is characterized during summer as having a hot, humid, sub-tropical climate.

**Feeding Management**

In the 3 mo before the start of the study, cows were on pasture. Three weeks before their due date for calving, springer cows were moved to a new paddock (springer paddock) adjacent to the feedpad and fed a springer TMR with ad libitum access to cereal hay. The animals had free access to fresh water and the paddock was well shaded by mature trees. On entering the study (i.e., when they entered the milking herd and moved to feedpad), approximately 24 h after calving, all cows had ad libitum access to a TMR that was provided on a shaded feedpad. Fresh feed was provided daily at 0500 and 1700 h. Residual feed was collected and weighed before the 1700 h feeding. Water was also available ad libitum. The diet ingredients and nutrient profile on a DM basis are provided in Table 1.

**Treatments**

Two treatments (n = 60 cows/treatment; 2 pens/treatment with 30 cows per pen) were imposed: (1) day cooling (DC), which included overhead sprinklers (large droplet) and fans while in dairy holding yard, plus ducted air blowing onto cows during milking (see below for details), plus shade and fans at the feedpad,
and a shaded loafing area; and (2) enhanced day+night cooling (EDN), which included overhead sprinklers (large droplet) and fans in dairy holding yard, plus thorough wetting (shower array) on exit from dairy, plus shade and overhead fans at feedpad, and shaded loafing area plus ducted fan-forced air blowing onto cows at night. In EDN, the fans at the feedpad were turned off at night. Both treatments had access to drinking water in the holding yard before milking and on exit from the dairy.

Cows entered the study 24 h after they had calved, so numbers per treatment and per pen increased from the start of the study and reached a maximum around d 40 of the study. The cows remained within their treatment groups for the duration of the study unless they were removed for veterinary treatment.

**Milking Parlor and Holding Yard**

The cows were managed within their respective treatment groups; that is, each group was milked separately. The cows were walked via an unshaded laneway approximately 500 m from the feedpad to the holding yard, approximately 30 min before milking, and were allowed to returned to the feedpad after milking. The cows were milked twice daily between 0500 and 0600 h, and between 1600 and 1700 h. Milking cups were fitted with in-line milk meters (Metatron 12, Westfalia Surge, GEA Farm Technologies). This allowed for individual daily milk production records to be obtained using DairyPlan software (DairyPlan, Westfalia Surge). Milking occurred in a 14-per-side herringbone-design dairy parlor, equipped with hydraulic exit gates on each side. The cows were not given access to supplementary feeds during milking. An air duct (10 m long, with 13 downward-facing outlets 80 mm in diameter) was located above each milking bay. The duct was sealed on one end with a 0.67-kW, 4-bladed, 800-mm-diameter fan (Hydor Fans and Ventilation Equipment) on the other end. The duct was placed 3.0 m above the floor. Airspeed was measured using an anemometer (Kestrel 3500DT, Kestrel Australia East Melbourne) every 2 wk on Mondays at 1500 h just before milking. The mean air speed exiting from the holes was 2.9 ± 0.8 m/s at 1.5 m above the floor. The covered holding area (25 m × 12.5 m × 4.5 m, length × width × height) had 3 overhead fans (800 mm diameter; Hydor Fans and Ventilation Equipment), and an additional 2 fans of the same size and type were located at the entrances to the milking bays (one for each bay), which forced air onto the cows while they were being milked. The fans ran constantly when cows were in the holding yard and while they were being milked. Ten large-droplet sprinklers were located 2.0 m above the cows in the holding area. The sprinklers were automatically timed for alternating periods of 45 s of water application and 45 s of no application. Two water troughs were located within the holding area, and 1 was located 5 m from the exit gate at the end of the exit lane.

The shower array consisted of 6 brass garden hose nozzles (2.5 m above the floor) attached to polypropylene pipe, all of which was attached to a metal frame; the spray covered an area of 2.5 × 2.5 m (Figure 1). The array was set up so that the EDN cows could not avoid the water application, and it was manually activated at both morning and afternoon milking when daily maximum temperature-humidity index (THI) was predicted to or did exceed 75 units.

**Feedpad and Loafing Area**

The shaded feedpad was 59.5 m long × 16 m wide × 4 m high with a north–south orientation. Four pens (see below) were set up to allow approximately 29.75 m of linear feeding space per pen (i.e., half of one side of the feedpad). The feedpad provided 24.4 m² of shade per pen. Additional shade was provided in the loafing area by 2 solid-roof shade structures (59.5 m long × 6 m wide × 4 m high), one located on the western side of the feedpad and the other on the eastern side. Each trial pen had access to half of one shade structure (29.75 m × 6 m), thereby providing 178.5 m² of shade. When the pens were full (30 cows/pen), there was approximately 6.8 m² of shade/cow. Bedding under the shade structures was composted manure.

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**Table 1. Ingredients and chemical composition of the TMR**

<table>
<thead>
<tr>
<th>Item</th>
<th>% of DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingredient</td>
<td></td>
</tr>
<tr>
<td>Alfalfa hay</td>
<td>22.54</td>
</tr>
<tr>
<td>Corn silage</td>
<td>33.22</td>
</tr>
<tr>
<td>Canola meal</td>
<td>11.31</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>8.26</td>
</tr>
<tr>
<td>Wheat grain</td>
<td>22.29</td>
</tr>
<tr>
<td>Vitamin/mineral mix¹</td>
<td>2.38</td>
</tr>
<tr>
<td>Chemical composition</td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>60.99</td>
</tr>
<tr>
<td>CP</td>
<td>18.40</td>
</tr>
<tr>
<td>NDF</td>
<td>32.31</td>
</tr>
<tr>
<td>ADF</td>
<td>22.43</td>
</tr>
<tr>
<td>NFC</td>
<td>41.43</td>
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<tr>
<td>Starch</td>
<td>27.03</td>
</tr>
<tr>
<td>Sugar</td>
<td>4.88</td>
</tr>
<tr>
<td>Lignin</td>
<td>4.45</td>
</tr>
</tbody>
</table>

¹Each 50-g dose contained vitamin A 52,000 IU, copper 160 mg, vitamin D₃ 4,000 IU, iron 200 mg, vitamin E 120 IU, manganese 320 mg, iodine 3.2 mg, zinc 1,000 mg, selenium 5 mg, magnesium 8 g, cobalt 10 mg, and sodium 8 g. Total buffers 45 g (as magnesium oxide and sodium bicarbonate).
Pen Setup

The pens were set up at the feedpad, and treatment groups were separated by electric fencing (Figure 2). The pens were identified as east-side pens (E1 and E2) and west-side pens (W1 and W2). The feedpad was oriented approximately north–south. Cows (within each treatment group and pen) changed pens each morning following milking in an effort to remove any confounding effects due to pen. The order of pen changes was E1 (29.2 m × 36.4 m) to E2 (36.4 m × 69.6 m), E2 to W2, W2 (36.4 m × 69.6 m) to W1 (29.2 m × 36.4 m), and W1 to E1.

Loafing Area Ducted Air Array

Each ducted air array was 12 m long with a diameter of 800 mm and was made of white polyurethane, waterproof woven fabric suspended within a steel frame attached to the underside of the loafing area shade structure (Figure 3). Along the length of the bottom side of the air duct, 15 holes were spaced approximately 80 cm apart; each hole had a diameter of 80 mm. A 4-bladed, 0.55-kW fan (Stir Fan, model 163-00018, Stockyard Industries) was fixed to one end of the air duct, and the other end of the air duct was sealed, so that air was directed downward from the holes toward cattle resting along the loafing area. Airspeed was measured every 2 wk, on Mondays at 1300 h using an anemometer (Kestrel 3500DT, Kestrel Australia East Melbourne). The mean air speed exiting from the holes (all ducts combined) was 2.58 ± 0.16 m/s at 1.0 m above the floor. The air speed decreased from hole 1 (3.21 m/s) to hole 15 (1.5 m/s). The duct fans were manually turned on between 2030 and 2100 h (after the last cattle observations of the day) when the maximum daily THI was ≥75, and then turned off at approximately 0430 h (after the first round of cattle observations for the following day); that is, a period of approximately 7 h, and just before the cows were moved to the holding yard for milking. The ducted air arrays were attached to the both the eastern (n = 4) and western (n = 4) shaded loafing areas located either side of the feedpad.

Rumen Boluses

Radio-transmitting reticulo-rumen temperature (T_{RUM}) boluses (SmaXtec Premium Bolus were administered per os to 40 cows per treatment group 1 to 2 mo before the commencement of the study. All boluses were tested in a 39°C water bath for 24 h, and then tested in a 41°C water bath for a further 24 h before placement in the cows. The boluses have a relative measurement accuracy of ±0.05°C at 39°C. They are cylindrical (33 mm diameter by 130 mm in length) and weigh approximately 220 g. They have an internal memory capacity of 50 d, and need to be connected to Wi-Fi for data downloading, which occurred each time the cows entered the milking facility. Rumen temperatures were obtained at 10-min intervals over the duration of the study. In addition to rumen temperature, the boluses also measured cow activity. Activity was determined via an accelerometer at 10-min intervals and was not affected by rumen motility (Stein et al., 2017).

Mean Panting Score

The mean panting score (MPS) of a group of animals can be used to determine the severity of heat stress (Gaughan et al., 2010a) for a group of animals. The MPS is determined by observing individual panting scores of a group of cows and then averaging the individual scores to obtain a mean for the group (Gaughan et al., 2008b). Individual scores were used to determine the percentage of cows within each treatment within panting score (PS) categories: PS = 0, PS = 1, PS ≥
1.5 < 2.5, PS ≥ 2.5 < 3.5, and PS ≥ 3.5 (Lees et al., 2018b). For dairy cows, we used an additional scoring point PS = 1.5 to account for their lower heat tolerance relative to beef breeds, from which the PS index used was developed. Cows with individual scores ≤1.5 (i.e., PS = 0 and PS = 1) were not considered heat stressed (Gaughan et al., 2010a). Cows with PS ≥1.5 were deemed to be heat stressed; those in the range PS ≥ 1.5 < 2.5 were considered to be under moderate heat load, those with PS ≥ 2.5 < 3.5 were considered to be under high heat load, and those with PS ≥ 3.5 were considered to be under extreme heat load. The rationale for using MPS rather than respiration rates was that to be close enough to determine individual animal respiration rates, the observer’s presence would change the cow’s behavior. Individual panting scores ranged from 0 = no panting; 3 = open mouth and excessive drooling, neck extended, head up tongue not extended, excessive drooling; and 4.5 = head held down, cattle “breath” from flank, drooling may cease (Mader et al., 2006; Gaughan et al., 2008a; Table 2). For the present study, MPS were used to describe the following 4 stress categories: (1) no stress, MPS score between 0 and <0.4; (2) low stress, MPS ≥0.4 and <0.8; (3) high stress, MPS ≥0.8 and <1.2; and (4) severe stress, MPS ≥1.2 (Gaughan et al., 2010b).

Figure 2. Pen layout. W1 = west 1, W2 = west 2, E1 = east 1, E2 = east 2; shaded area is the covered feedpad; X = location of weather station; O = approximate placement of water troughs. The black lines represent electric fencing.

Figure 3. Fans at the feedpad (A), and fan-forced air ducts in the shaded loafing area (B).
Weather Data

Ambient temperature (TA, °C), relative humidity (RH, %), wind speed (m/s), black globe temperature, and solar radiation (W/m²) were obtained every 10 min by an automated weather station (Davis Vantage Pro 2, Davis Instruments) located 5 m from the northern end of the feedpad. Rainfall (mm) was measured daily at 0900 h. The THI was calculated from ambient temperature and relative humidity data, as follows:

\[
\text{THI} = \left[0.8 \times T_A\right] + \left[(RH/100) \times (T_A - 14.3)\right] + 46.3
\]

(Thom, 1959). Three temperature sensors (Hobo U12-008, Onset Computer Corp.) were placed in 3 black globes and set up under the shade structures on the west and east sides of the feedpad.

Heat Wave Definition

For this study, a heat wave was defined as 3 or more days when the maximum THI was ≥79, the minimum THI ≥68, and there were ≥3 h within a 24-h period (0000 h to 2359 h) where THI hours ≥79. Herein, THI hours is defined as the summation of the differences between the observed THI and the base (in this case, 79) at each hour of the day (Hahn and Mader, 1997). For example, THI hours = 7:30 means that THI ≥79 for 7 h and 30 min in a 24-h period. A THI threshold between 80 and 89 is considered to indicate moderate to severe heat stress, and >89 is severe heat stress (Renaudeau et al., 2012). A THI of ≥68 is considered the heat stress threshold for dairy cows (Bouraoui et al., 2002; Renaudeau et al., 2012). A THI between 68 and 71 is considered low stress and a THI below 68 indicates no stress.

Statistical Analysis

Data were analyzed across the whole of the study, and a separate analysis (same variables used) was undertaken for a heat wave event. Data were used from 58 of the EDN cows and 51 of the DC cows for all criteria. Eleven cows (9 from DC and 2 from EDN) were removed from the study due to health problems; 2 cows with mastitis (EDN), 2 cows with mastitis (DC), 1 cow with lameness (DC), 2 cows (DC) with calving difficulties (immediately before entry into the study), and 4 cows (DC) due to lack of sufficient data (e.g., late calving, equipment failure), and their associated data sets were discarded. Data were analyzed (unless otherwise stated) using a repeated-measures linear mixed effects model using REML estimation (SAS Institute Inc.). All models included individual cow identification (cow ID) as a random effect. Data are presented as least squares means ± standard errors. When significance was indicated (P < 0.05), means were separated using Tukey's Studentized range test.

MY. Milk yield (corrected for DIM) was analyzed. Days in milk were categorized as DIM category (DIMCAT) 1, ≤20 DIM; DIMCAT 2, >0, ≤40 DIM; DIMCAT 3, >40, ≤60 DIM; and DIMCAT 4, >60 DIM. Treatment means were corrected for DIM.

TRUM. Ten-minute individual TRUM data were converted to an hourly average for each individual cow. Pooled mean hourly TRUM data were then calculated, establishing a diurnal rhythm. The TRUM data were analyzed using first-order autoregressive repeated measures and a linear mixed effects model. The model included treatment, pen, time of day (hour), day, treatment × day, and treatment × hour as fixed effects.

MPS. The repeated-measures linear mixed effects model incorporated DIM, pen, time of time of day [0430 h (AM1), 0930 h (AM2), 1530 h (PM1), and 2030 h (PM2)], treatment, treatment × time of day, day × treatment, and DIM × time of day × treatment as fixed effects.

DMI. Group average DMI was calculated based on total amount of feed offered per day per treatment divided by cows in each pen. However, as DMI was not measured individually, it was not possible to sepa-

Table 2. Panting score and breathing condition

<table>
<thead>
<tr>
<th>Panting score</th>
<th>Breathing condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No panting</td>
</tr>
<tr>
<td>1</td>
<td>Slight panting, mouth closed, no drool, slight chest movement</td>
</tr>
<tr>
<td>1.5</td>
<td>Fast panting, mouth closed, no drool, easy to see chest movement</td>
</tr>
<tr>
<td>2</td>
<td>Fast panting, drool present, no open mouth</td>
</tr>
<tr>
<td>2.5</td>
<td>As for 2, but occasional open-mouth panting, tongue not extended</td>
</tr>
<tr>
<td>3</td>
<td>Open mouth and excessive drooling, neck extended, head held up</td>
</tr>
<tr>
<td>3.5</td>
<td>As for 3 but with tongue out slightly and occasionally fully extended for short periods</td>
</tr>
<tr>
<td>4</td>
<td>Open mouth with tongue fully extended for prolonged periods with excessive drooling; neck extended and head up</td>
</tr>
<tr>
<td>4.5</td>
<td>As for 4 but head held down; cattle “breath” from flank; drooling may cease</td>
</tr>
</tbody>
</table>

1Lees et al. (2018a); Mader et al. (2006); and Gaughan et al. (2008b).
rate treatment differences for DMI; as such, treatment means ± SE are presented.

RESULTS

Weather

In the 3 mo before the start of the study, when the pregnant cows were housed on pasture, the climate conditions were slightly above long-term averages. Mean ± SE (maximum and minimum temperature) temperatures for October, November, and December were 20.04 ± 0.13°C (36.1°C, 7.3°C), 23.54 ± 0.16°C (39.0°C, 9.0°C), and 24.95 ± 0.14°C (40.7°C, 12.0°C), respectively. There was 1 d in October, 4 d in November, and 8 d in December when maximum temperatures were ≥35°C. The mean THI ± SE (maximum minimum) were 65.74 ± 0.17 (81.02, 45.56) for October, 69.21 ± 0.18 (85.24, 49.21) for November, and 71.98 ± 0.15 (85.99, 53.85) for December. The maximum THI was ≥75 on 19 d in October, on 21 d in November (6 of which were ≥80), and on 28 d in December (10 of which were ≥80). Rainfall was above the long-term average (shown in parentheses) during October at 169.8 mm (65.2 mm), and December at 134.0 mm (98.2 mm). Rainfall in November was below average, at 42.2 mm (77.3 mm).

Overall, the months of January, February, and March were hotter than the long-term averages, whereas conditions for April were close to the long-term averages (Table 3; Figure 4). The daily THI ranged from 63.3 to 83.5, 61.3 to 84.8, 56.9 to 83.9, and 54.9 to 78.6 for January, February, March, and April, respectively. There were 30 d in January when the maximum THI was ≥75, followed by 28 d in February, 26 d in March, and 14 d in April (Figure 5). Rainfall was below average for January at 19.1 mm (long-term average: 109.7 mm), February at 19.0 mm (99.6 mm), and April at 13.7 mm (48.2 mm); however, rainfall for March was above average, at 173.0 mm (79.8 mm).

Heat Waves

Four periods met the heat wave criteria (Figure 5). These were January 20 to February 2 (14 d; heat wave 1: mean maximum TA = 35.32°C); February 8 to 15 (8 d; heat wave 2: mean maximum TA = 35.84°C); March 6 to 13 (8 d; heat wave 3: mean maximum TA = 37.00°C); and March 20 to 26 (7 d; heat wave 4: mean maximum TA = 34.07°C). During heat wave 1, the THI hours exceeded 9 h on 1 d, 7 h on 6 d, and 6 h on 3 d during the event. During heat wave 3, which was the most severe event, THI hours exceeded 6 h on 7 d, 7 h on 5 d, and ≥9 h on 3 d. During heat wave 3, THI hours exceeded 9 h on 3 d, 7 h on 3 d, and 6 h on 1 d. The fourth heat wave was mild compared with the first 3. The THI hours exceeded 7 h on 1 d and 6 h on 3 d. Calving commenced mid-January and, as such, only a few cows had entered the study at the time of the first heat wave. All cows were in the study (i.e., had calved) by the start of the third heat wave. Data from heat waves 1, 2, and 4 are not included in the specific heat wave analysis described in this article, as these data are presented elsewhere.

Study Effects (90 d) on DMI, MY, MPS, and TRUM

**DMI.** Group average DMI was calculated based on total amount of feed offered per day per treatment divided by cows in pens. The EDN cows consumed on average 21.23 ± 0.52 kg/d, and DC cows consumed 20.95 ± 0.52 kg/d.

**MY.** The mean MY of the EDN cows was 2.05 kg/cow per day greater (P < 0.0001) than the DC group (Table 4). There was a treatment × DIMCAT interaction (P = 0.0368; Figure 6): EDN cows had higher MY for
DIMCAT 2 ($P < 0.0001$) and DIMCAT 3 ($P = 0.0148$), both of which corresponded with the hottest part of the study. There was a trend ($P = 0.0981$) for greater MY in EDN cows for DIMCAT 1.

**MPS.** The MPS for the EDN cows was lower ($P = 0.0060$) than that of DC cows at 0.68 ± 0.02 and 0.75 ± 0.02 units, respectively (Table 4). Although the difference was statistically different, it may not be of biological significance. The distribution (percentage of cows within each PS category) is presented in Figure 7. The higher percentage of cows within the PS = 0 and PS = 1 categories indicates that there is a lower percentage of cows in the high to severe stress categories. In addition to the treatment effects, there was also a time of day ($P < 0.0001$) effect on MPS. However, there were no treatment × time of day effects ($P = 0.7990$; Table 5). Cows experienced increased heat load for most of the study period. For both treatments, MPS

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**Figure 4.** Ambient temperature (TA, °C), black globe temperature (BG, °C), and relative humidity (RH, %) for the period from January 1 to April 23, 2019; the x-axis indicates dates in dd/mm/yy format.
were in the low stress category (≥0.4 to 0.8) for AM1 and PM2, and in the high stress category (≥0.8 to 1.2) during AM2 and PM1.

Treatment \( (P = 0.0325) \) and pen \( (P = 0.0032) \) differences were detected for MPS. The EDN cows had lower MPS than the DC group for both west pens but not for the east-facing pens. When cow groups were combined, the mean MPS were greater \( (P < 0.05) \) in W1 and E1 compared with W2 and E2. Within pens, the MPS were as follows: W1 pen: DC > EDN; W2 pen: DC > EDN; E1 pen: DC = EDN; and E2 pen: DC = EDN. Between pens, the MPS were as follows: DC in W1 = EDN and DC in E2 = EDN; DC in W2 > EDN and DC in E1 = EDN; DC in W1 > EDN and DC in E2. The W1 and E1 pens both had longer sun exposure during the day, which may explain the greater MPS. These data highlight the importance of microclimate effects even over relatively small distances.

**TRUM.** Reticulo-rumen temperature was lower \( (P < 0.0001) \) for EDN cows, which had a mean \( T_{\text{RUM}} \) of 39.51 ± 0.01°C (range: 37.92 to 41.09°C) compared with DC cows, with a mean of 39.66 ± 0.01°C (range: 37.98 to 41.21°C; Table 4; Figure 8). There were also treatment \( \times \) time of day interactions \( (P < 0.0001; \text{Table 6}) \).

Rumen temperature is presented using an hour code, as follows: 1 = 0000 to 0559 h, 2 = 0600 to 1159 h, 3 = 1200 to 1759 h, and 4 = 1800 to 2359 h. The \( T_{\text{RUM}} \) decreased between 0400 and 0700 h for both treatments. The reduction in the DC cows was 0.82°C (0.27°C/h) and that for EDN cows was 0.68°C (0.23°C/h). From 0700 h, \( T_{\text{RUM}} \) increased in DC from 38.95°C and reached a peak of 40.00°C at 1400 h, an increase of 1.05°C. The \( T_{\text{RUM}} \) of the EDN cows increased from 38.98°C at 0700 h and reached a peak of 39.79°C at 1500 h. The \( T_{\text{RUM}} \) increased by 0.15°C/h and 0.10°C/h, respectively, for DC and EDN. Over the duration of the study, the DC group averaged 4 h/d when \( T_{\text{RUM}} \) was <39.5°C, and the EDN cows averaged 7 h/d.

**Effects of Third Heat Wave on PS, \( T_{\text{RUM}}, \text{MY, and DMI} \)**

**Panting Score.** There were no treatment differences \( (P = 0.6948) \) for MPS during the third heat wave, with EDN and DC having scores of 1.09 ± 0.06 and 1.13 ± 0.06, respectively. The distribution (percentage of cows within each PS category) are presented in Figure 9. There was a greater percentage of DC cows within the moderate (47.87% vs. 27.48% for EDN), severe (3.3% EDN and 2.72% DC), and extreme (0.31% EDN and
0.76% DC) heat load categories (Figure 9). The higher percentage of DC cows in the moderate heat load category means that there are fewer DC cows in the severe and extreme categories. There were day effects ($P = 0.0072$) but no treatment × day effects ($P = 0.8136$). During AM1, MPS were $1.23 \pm 0.11$ and $1.31 \pm 0.11$ for EDN and DC, respectively; during PM1, MPS were $1.57 \pm 0.11$ and $1.59 \pm 0.11$ for EDN and DC, respectively. During the 6-d period following the heat wave, EDN cows had a lower ($P = 0.0197$) MPS than DC cows ($0.75 \pm 0.07$ and $1.01 \pm 0.07$, respectively). There was also a time of day effect ($P = 0.0008$), but no treatment × time of day effect ($P = 0.5889$). However, there was a tendency for EDN cows to have a lower ($P = 0.0845$) MPS during PM2 ($0.91 \pm 0.17$) compared with the MPS for DC cows ($1.33 \pm 0.17$).

**TRUM.** The additional cooling resulted in a reduction in $T_{RUM}$ in EDN cows during the heat wave. The EDN cows had lower $T_{RUM}$ ($P < 0.001$) than DC cows on each day of the 8-d heat wave (Table 7; Figure 10). The mean $T_{RUM}$ during the heat wave was $39.58 \pm 0.01^\circ C$ and $40.10 \pm 0.01^\circ C$, respectively, for EDN and DC. During the 2 h following the PM milking (1600 to 1800 h), the $T_{RUM}$ of EDN was $39.71 \pm 0.02^\circ C$ compared with $40.43 \pm 0.02^\circ C$ ($P < 0.0001$). From 1800 to 2000 h, the $T_{RUM}$ of EDN was $39.69 \pm 0.02^\circ C$ compared

---

**Table 4.** Means (±SE) for milk yield, DIM, rumen temperature (°C), and mean panting score (MPS) for the duration of the study

<table>
<thead>
<tr>
<th>Item</th>
<th>EDN (n = 58)</th>
<th>DC (n = 51)</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIM</td>
<td>63.76 ± 1.12 $^a$</td>
<td>60.48 ± 0.29 $^a$</td>
<td>0.6827</td>
</tr>
<tr>
<td>Milk yield, kg/cow per day</td>
<td>28.74 ± 0.18 $^a$</td>
<td>26.69 ± 0.24 $^a$</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Rumen temperature, °C</td>
<td>39.51 ± 0.01 $^a$</td>
<td>39.66 ± 0.01 $^a$</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>MPS</td>
<td>0.68 ± 0.02 $^a$</td>
<td>0.75 ± 0.02 $^a$</td>
<td>0.0060</td>
</tr>
</tbody>
</table>

$^a$Means within a row with different superscripts are significantly different ($P < 0.05$).

$^1$EDN = enhanced day and night cooling (overhead large-droplet sprinklers and fans in the dairy holding yard, plus ducted air blowing onto cows during milking, plus thorough wetting from a shower array on exit from dairy, plus shade and overhead fans at feedpad, and shaded loafing area plus ducted air blowing onto cows at night); DC = day cooling (overhead large-droplet sprinklers and fans while in the dairy holding yard, plus ducted air blowing onto cows during milking, plus shade and fans at the feedpad, and a shaded loafing area.

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**Figure 7.** Percentage of cows within each panting score (PS) category over the duration of the study. EDN = enhanced day+night cooling; DAY = day cooling; see Table 4 for a complete description of cooling treatments. 0 = no panting; 1 = slight panting; mouth closed, no drool, slight chest movement; 1.5 = fast panting, mouth closed, no drool, easy to see chest movement; 2 = fast panting, drool present, no open mouth; 2.5 = as for 2, but occasional open-mouth panting, tongue not extended; 3 = open mouth and excessive drooling, neck extended, head up; 3.5 = as for 3 but with tongue out slightly and occasionally fully extended for short periods; 4 = open mouth with tongue fully extended for prolonged periods with excessive drooling; neck extended and head up; 4.5 = as for 4 but head held down; cattle “breath” from flank; drooling may cease.
with 40.23 ± 0.02°C for DC (P < 0.0001). The greatest decrease in TRUM occurred in both treatments between 0400 and 0700 h. During this 3-h period, TRUM of EDN decreased by 0.73°C (0.24°C/h). There was a slightly greater reduction (−0.86°C) for DC (0.29°C/h). For both treatments, TRUM increased from 0700 h to reach a maximum at 1400 h (39.88°C and 40.68°C, respectively, for EDN and DC. This was a 1.53°C increase (0.22°C/h) for DC and a 0.91°C increase (0.13°C/h) for EDN. The EDN cows had, on average, 6 h/d during the heat wave when TRUM was <39.5°C, whereas DC cows had only 3 h/d when TRUM was <39.5°C. In the 6 d following the heat wave, TRUM was greater (P < 0.001) for EDN than for DC (39.73 ± 0.02 and 39.64 ± 0.02°C, respectively).

**MY.** Over the 6 d before the heat wave, MY were 27.88 ± 0.40 and 25.38 ± 0.36 kg/d, respectively, for EDN and DC (P = 0.0487), a difference of 2.50 kg/d. During the heat wave, MY were 27.05 ± 0.40 and 25.81 ± 0.32 kg/d (a difference of 1.24 kg/d), respectively, for EDN and DC (P = 0.3888). However, over the 6 d following the heat wave, MY were greater (P = 0.0327) for the EDN cows (29.14 ± 0.48 kg/d) than for the DC cows (25.33 ± 0.30 kg/d), a difference of 3.61 kg.

**DMI.** Dry matter intakes were similar between treatments during the heat wave: 24.12 ± 0.56 and 23.65 ± 0.98 kg/d, respectively, for EDN and DC cows. Over the 6 d following the heat wave, DMI was 26.98 ± 1.43 kg/d for EDN cows and 24.67 ± 0.66 kg/d for DC cows. Over the 6 d following the heat wave, DMI was 26.98 ± 1.43 kg/d for EDN cows and 24.67 ± 0.66 kg/d for DC.

### DISCUSSION

This study is, to our knowledge, the first to investigate the potential of using ducted air as a means of cooling cows in an open pen environment at night.
Providing cooling for nonhoused dairy cows (i.e., cows on feedpads or in pasture) presents a challenge. The benefits of sprinklers and fans for cooling cattle were first established by Sheath and Miller (1948), and this strategy has been used for over 30 yr as a method to reduce heat stress (Flamenbaum et al., 1986) in both housed dairy cows and cows in outside yards. Evaporative heat loss from the skin and sensible heat losses are affected by relative humidity, the temperature gradient between the cow and the environment, and air velocity across the body surface of the cow (Berman, 2006). The efficiency of cooling over a range of environmental conditions (temperature and relative humidity) is improved if air velocity at the animal is 1 to 1.5 m/s (Berman, 2006). During the current study, the airflow exiting the tubes was 2.9 ± 0.8 m/s, which is twice the rate described by Berman (2006) needed to improve heat loss efficiency. During periods when natural air velocity is low and temperature and humidity are high, forced air flow may be required to ensure adequate cooling of cows. The use of fans in outdoor environments is often inefficient due to rapid dispersal of the air being moved by the fans.

The use of fan-forced ducted air as a means of cooling livestock is not new (Carpenter, 1972). The use of ducted air systems using woven polythene fabric tubing was often used to improve direct air flow onto pigs (Taylor et al., 1994). The use of ducted air to cool livestock has been exclusively used within fully or partially enclosed buildings. Ducted air systems are also used for ventilation and to draw air from outside the building to the inside. These systems do not cool the air but simply increase the air speed across the animals; they should not be confused with tunnel ventilation systems. Ducted systems typically do not draw air from outside the facility but use fans attached to one end of the duct to force air through holes on the bottom of the duct, which forces the air downward onto the target animals. The efficacy of ducted air to improve cooling of cows in an open environment may be influenced by natural airflow (Mondaca, 2019). It is possible that high natural airflow will negate the effect of ducted air, although this

### Table 6. Treatment × time of day effects (hour code) on rumen temperature (TRUM) for the duration of the study

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Hour code</th>
<th>TRUM, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDN</td>
<td>1</td>
<td>39.57 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>DC</td>
<td>1</td>
<td>39.66 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>EDN</td>
<td>2</td>
<td>39.20 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>DC</td>
<td>2</td>
<td>39.36 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>EDN</td>
<td>3</td>
<td>39.63 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>DC</td>
<td>3</td>
<td>39.84 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>EDN</td>
<td>4</td>
<td>39.64 ± 0.01&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>DC</td>
<td>4</td>
<td>39.78 ± 0.01&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a,b</sup>Treatment means within an hour code with different superscripts are significantly different (P < 0.0001).

<sup>1</sup>EDN = enhanced day+night cooling; DC = day cooling; see Table 4 for a complete description of cooling treatments.

<sup>2</sup>Where 1 = 0000 to 0559 h, 2 = 0600 to 1159 h, 3 = 1200 to 1759 h, and 4 = 1800 to 2359 h.
Effect of EDN on Physiological Responses

Milk Production. Reduction in milk yield is a common occurrence when dairy cows are subjected to high heat loads (Collier et al., 1982). Strategies to reduce heat load such as fans, sprinkler, cooled air, and various combinations of these have been used to reduce the impact of heat on milk production. Although all of these strategies will reduce the negative effect on milk yield, there is little evidence to show that milk production recovers sufficiently following a heat event. Drwencke et al. (2020) using 4 heat abatement strategies for dairy cows, including ducted evaporatively cooled air (21.0 ± 3.7°C) air within an open-sided barn. In that study, the ducted air treatment did not lead to an improvement in

Table 7. Treatment differences for rumen temperature (TRUM), maximum and minimum THI units (THI_MAX and THI_MIN), and THI hours ≥79 units over an 8-d heat wave (heat wave 3)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Day</th>
<th>TRUM, °C</th>
<th>Difference, °C</th>
<th>THI_MAX</th>
<th>THI_MIN</th>
<th>THI hours ≥79, hh:mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDN 1</td>
<td>1</td>
<td>39.47 ± 0.03 °C</td>
<td>0.38</td>
<td>81.94</td>
<td>68.5</td>
<td>7:30</td>
</tr>
<tr>
<td>DC</td>
<td>2</td>
<td>39.85 ± 0.03 °C</td>
<td>0.45</td>
<td>81.86</td>
<td>68.1</td>
<td>7:00</td>
</tr>
<tr>
<td>EDN 3</td>
<td>3</td>
<td>39.58 ± 0.03 °C</td>
<td>0.28</td>
<td>79.95</td>
<td>68.9</td>
<td>3:10</td>
</tr>
<tr>
<td>DC</td>
<td>4</td>
<td>39.86 ± 0.03 °C</td>
<td>0.60</td>
<td>81.17</td>
<td>68.6</td>
<td>6:10</td>
</tr>
<tr>
<td>EDN 5</td>
<td>5</td>
<td>39.50 ± 0.03 °C</td>
<td>0.45</td>
<td>81.94</td>
<td>68.5</td>
<td>9:00</td>
</tr>
<tr>
<td>DC</td>
<td>6</td>
<td>39.56 ± 0.03 °C</td>
<td>0.65</td>
<td>81.94</td>
<td>68.5</td>
<td>10:50</td>
</tr>
<tr>
<td>EDN 7</td>
<td>7</td>
<td>39.67 ± 0.03 °C</td>
<td>0.82</td>
<td>83.94</td>
<td>69.6</td>
<td>7:20</td>
</tr>
<tr>
<td>DC</td>
<td>8</td>
<td>39.67 ± 0.03 °C</td>
<td>0.57</td>
<td>83.79</td>
<td>71.2</td>
<td>9:00</td>
</tr>
<tr>
<td>DC</td>
<td></td>
<td>39.93 ± 0.03 °C</td>
<td>0.26</td>
<td>83.12</td>
<td>62.8</td>
<td>7:00</td>
</tr>
</tbody>
</table>

*a,b* Means for TRUM within a day with different superscripts are significantly different (*P* < 0.001).

EDN = enhanced day+night cooling; DC = day cooling; see Table 4 for a complete description of cooling treatments.

Figure 10. Mean hourly rumen temperature of enhanced day+night cooling (EDN; gray line) and day cooling (DC; black line) cows during heat wave 3 (8 d). See Table 4 for a complete description of cooling treatments. Treatment means at all time points differ (*P* < 0.0001). Cows walked to the milking parlor at 0430 and 1500 h and returned to the feedpad at 0630 and 1630 h. The dotted line is the mean hourly temperature-humidity index.
milk production. In contrast, in the current study, we found greater milk production for the cows with access to a shower on exit from the dairy and the ducted air in a feedpad environment across the duration of the study (+2.05 kg/cow per day). Six days before the third heat wave, the EDN cows were producing 2.50 kg/d more than the DC cows. Although there was little difference between treatments during the third heat wave (MY 1.24 kg/d greater for EDN), over the 6 d following the heat wave, milk production was greater in the EDN cows (3.61 kg/cow per day), and EDN cows maintained the advantage for the rest of the study. It is evident that enhanced cooling during the heat wave allowed the EDN cows to recover faster that the DC cows. Although the major aim during a heat wave is to reduce negative effects on health, well-being, and performance, recovery after a heat event is important; that is, animals need to return, as close as possible, to performance before the heat wave, without any negative effects on health and well-being.

**Rumen Temperature.** Gonzalez-Rivas et al. (2018) reported a mean rumen temperature of 39.3 ± 0.14°C for cows that were exposed to the UQ dairy’s standard cooling strategies (i.e., similar to DC in the current study). The T_{RUM} in the current study were slightly greater, at +0.21°C for EDN and +0.36°C for DC, than the values of Gonzalez-Rivas et al. (2018). Higher mean T_{RUM} (40.02°C) were reported in a study using high-production Holstein cows (milk production = 35.27 ± 8.44 kg/d; Liang et al., 2013). In that study, the higher T_{RUM} is most likely attributed to the higher metabolic rate of the higher-producing cows used compared with those of the current study. The largest decline in T_{RUM} occurred in the early morning (0400 to 0700 h), which was typically the coolest part of the day, and it is during this time that the temperature gradient between cow and environment allows the heat load of the cow to dissipate to the environment. This has been previously reported for beef cattle (Mader and Kreikemeier, 2006; Gaughan and Mader, 2014; Lees et al., 2018a) and for dairy cattle (Ammer et al., 2016). The cooling in the holding yard coupled with the temperature gradient between the cows and the environment suggest that additional cooling at this time needs to be further investigated. There may be benefits in using sprinklers at night for additional cooling, which will be enhanced by the temperature gradient. The greatest effect on T_{RUM} occurred during the heat wave. The additional cooling allowed the EDN cows to maintain T_{RUM} during the heat wave close to the average T_{RUM} over the duration of the study (39.58 vs. 39.51°C), and they were able to spend 6 h/d with T_{RUM} <39.5°C, which was only 1 h less than the overall average. In contrast, the DC cows had an elevated T_{RUM} of 0.52°C above the study average (40.10 vs. 39.58°C) during the heat wave. In the 6 d following the heat wave, the T_{RUM} of the EDN cows was greater than that of the DC cows (+0.09°C). Interestingly, the T_{RUM} of the EDN cows was lower during the heat wave than in the 6 d following the heat wave. It is likely that this was due to a combination of factors, such as the greater DMI, more time spent eating, and the greater milk production leading to an increase in metabolic heat production in the EDN cows during the 6-d period following the heat wave.

**PS.** Panting scores have been used in several studies as an assessment of the thermal status in beef cattle (Mader et al., 2006; Gaughan et al., 2008a,b; Melton et al., 2019; Lees et al., 2020) and dairy cows (Schütz et al., 2014; Gonzalez-Rivas et al., 2018; Lees et al., 2018a,b; Osei-Amponsah et al., 2020). In an earlier study at the UQ research dairy, Pearson correlation coefficients indicated strong relationships between respiration rate and PS (r = 0.89; P < 0.0001; our unpublished data). Similar results (r = 0.90; P ≤ 0.001) were reported by Osei-Amponsah et al. (2020). It has also been shown that PS increases as THI increases (Mader et al., 2006; Lees et al., 2018b; Osei-Amponsah et al., 2020). In the current study, EDN cows had a lower overall MPS than DC cows. Both treatment groups experienced low to high heat stress across most days, with severe stress (MPS ≥1.2) occurring on d 7 and 8 of the third heat wave for EDN and on d 6, 7, and 8 for DC. During the 6 d following the third heat wave, the lower MPS of the EDN cows suggests that their recovery from the heat wave was quicker than for the DC cows, but whether this was due to the cooling effect during the heat wave or the enhanced cooling after the heat wave is difficult to determine. The MPS was always lower for EDN cows than for DC cows; however, the additional cooling did not lead to reductions in PS during the day. Because of the study design, it was not possible to determine nighttime PS. Collecting 24-h respiratory data is an essential requirement for future studies. The use of PS without respiration rate data should be reconsidered because it does not permit fine-scale data analysis.

**Cost:Benefit Analysis**

The higher MY over the 106 d of the study equated to 217.3 kg/cow. Assuming that 1 L of milk is equal to 1.03 kg of milk, then 217.3 kg of milk = 223.82 L of milk. At an estimated payment of $0.476/L, the additional milk returns an income per cow of $106.54 over the 106 d. The cost of the ducted system was approximately $31,500. Based on 200 cows, the additional income was $21,308 (200 × $106.54), meaning that 67.7% of the installation cost was recovered over the first summer.
Integrity of Ducts in an Open Environment

High wind speed due to a storm caused damage to the initial duct setup. To counter this, we installed a metal frame around the ducts to reduce the effect of high winds. This worked well; however, a more robust system is required, especially in environments where severe storms are likely. Future studies will need to further investigate additional methods of protecting the air duct from strong winds, as well as optimal hole diameter and placement. There is also a need to investigate the option of using evaporatively cooled air within the system. Setting the ducted air fans to automatically turn on and off at a set THI threshold is recommended.

CONCLUSIONS

Over the duration of the study, EDN cows produced more milk and had lower rumen temperatures and reduced panting compared with DC cows. During the third and most severe heat wave, EDN cows had a lower mean $T_{\text{RUM}}$ over the heat wave’s 8-d duration compared with DC cows and had greater MY over the 6 d following the heat wave. Throughout the study, EDN cows spent more time lying than the DC cows. The combination of the shower array and the ducted air systems had a beneficial effect on milk production and cow welfare.

ACKNOWLEDGMENTS

This project would not have been undertaken without funding by Dairy Australia Ltd. (Southbank, Victoria, Australia); their support is gratefully acknowledged. The authors express their gratitude to all the staff at the UQ Dairy Research and Training Dairy (The University of Queensland, Gatton, Qld., Australia) for their support and assistance throughout the study. The authors have not stated any conflicts of interest.

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