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ORIGINAL PAPER

Fan cooling of the resting area in a free stalls dairy barn

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Abstract This summer study evaluated the effect of providing additional fans (cooling) in the resting area within a free-stall dairy barn that had fans and sprinklers in the feeding area and paddock availability. Thirty cows were divided into two homogenous groups and kept in two pens: one had the resting area equipped with two fans (FAN) while no fans were added to the other resting area (CON). Microclimatic parameters, rectal temperature (RT), breathing rate (BR), milk yield, and milk pH traits were recorded. Time budgeting and the behaviour of the cows (time spent in the feeding area, standing and lying in other areas) were also recorded using digital video technology. Two slight-to-moderate heat waves were observed. During the hottest period the daily maximum temperature recorded was 33.5 °C and the daily maximum THI was 81.6. During this period, the BR and RT increased only slightly in both groups, with lower BR (n.s.) in FAN compared with CON. Milk yield was better maintained (n.s.) in FAN compared with CON during the hottest period. The FAN cows showed a greater ($P<0.05$) lying time in the free stalls (9.5 and 8.6 h/day in FAN and CON, respectively), whereas CON cows made greater ($P<0.05$) use of the paddock during evening and late evening hours. Consequently, the total daily lying time was 13.5 h/day in both groups. In conclusion, the results suggest that using fans in the resting area improves cow comfort, which increases use of the resting area. The lying time results also suggest that the benefits of providing ventilation in the resting area might be more evident in barns where there is no paddock.

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Introduction

The problems of heat stress are important in a southern European country, such as Italy, in relation to the climatic conditions in summer, when high temperatures are coupled with high humidity. Prolonged exposure to high ambient temperature has a negative impact on the physiological balance of dairy cows (Bertoni 1998) through reduction of feed intake, increased nutritional requirements (Ronchi et al. 1997; Bernabucci et al. 2010; Wheelock et al. 2010), depressed production (Kadzere et al. 2002; West 2003) and reproductive efficiency (Jordan 2003; Wolfenson et al. 2000; Berman 1991), and negatively affects health and welfare (Cook et al. 2007; Lambert 2009; Marcillac-Embertson et al. 2009). Milk composition (Bernabucci and Calamari 1998), titratable acidity and milk technological quality (Calamari and Mariani 1998; Frazzi et al. 2002) are also negatively affected by heat stress.

The high production levels reached in our farms have also changed cattle's microclimatic needs, so the farmer needs to use the management strategies suggested by Beede and Collier (1986) to minimise the effects of heat stress. In particular, physical modification of the environment (adjustment of the barn structure, cooling) is considered the most effective. The system that has given the best results is cooling by direct wetting of the animal with water using sprinklers followed by forced ventilation (Flamenbaum et al. 1986; Gebremedhin and Wu 2000; Berman 2006). Many tests carried out in different countries have demonstrated the efficacy of this treatment, especially when the body surface of the animal is abundantly wetted and a high evaporation rate is maintained (Turner et al. 1992; Bickert and Stowell 1994; Calegari et al. 2005). The cooling by surface is relatively simple to carry out in the feeding area and in the waiting area of the milking parlour, where wetting of the floor has no direct significant negative consequences on the health of the animal. Conversely, this treatment does not seem suitable in the resting area, because wetting of the bedding could increase the bacterial load of the lying surface; which is related to the bacterial exposure of the teats and to the risk of environmental mastitis in relation to the type of bedding (De Palo et al. 2006).

Several tests have demonstrated that cooling of the feeding area alone does not totally eliminate the consequences of heat stress, as reviewed by Armstrong (2000). Cows remain standing longer in feeding areas that are equipped with cooling systems, rather than occupying other areas of the barn—especially the resting area (Barbari et al. 2012), causing tiredness and discomfort (Frazzi et al. 2000; Calegari et al. 2000). Lin et al. (1998) highlighted the importance of cooling the free-stall area, underlining caution as far as different beddings are concerned. More caution should be adopted when organic bedding is used. When using straw in the resting area, the better cooling system is forced ventilation without misting or sprinkling (Lin et al. 1998).

Animal behavioral modifications have been observed during heat stress; during the night cattle tend to go outside, and they spend a considerable part of the day standing rather than lying down (Frazzi et al. 2000 and 2002; Calegari et al. 2003). Recognized benefits of adequate resting time (up to 14 h/day for the most productive cows), including greater overall cow health and welfare, were highlighted by Grant (2006). The use of cooling systems both in the resting area and in the feeding area increases the time spent lying down in free stalls (Calegari et al. 2012). Observation of the time budgeting and behavior of cows, in particular the time spent lying and standing in the different areas of the barns, is useful to better understand the cow comfort related to the systems and equipment used in the barn (Calamari et al. 2009; Calegari et al. 2012). Our hypothesis was that the use of a cooling system (fans) in the resting area improves the time spent lying in the free stalls, with a positive effect on animal welfare.

The aim of our trial was to verify the effect of forced ventilation in the resting area on physiological, productive, and behavioral indices in mid-lactation cows during the summer season.

Materials and methods

Animal and management conditions

The trial was carried out in the summer season (from June to September 2006) in the experimental free-stall barn of the Azienda "V. Tadini", located near Piacenza, Italy (45°01′N, 9°40′E; altitude 68 m a.s.l.). In this two-row free-stall barn, 30 Italian Friesian lactating cows were kept in pens (11.5 × 12 m) hosting 15 cows each. The largest side of the barn (exposed to the west) was completely open to an unshaded hard-court paddock, while the other side was half-closed by a masonry wall.

Cows were fed total mixed ration (TMR) once daily ad libitum at 0800 h. The diet was formulated to meet the requirement calculated according to the NRC (2001). On average, the diet contained 42 % dry matter (DM) basis of corn silage, 17 % of alfalfa hay, and 41 % of concentrate (containing mineral and vitamins). Furthermore, the diet was supplied on average with 200 g/day per cow of sodium bicarbonate. The diet had an energy content of 1.59 Mcal/kg DM and crude protein content of 15.0 % on DM. Cows were milked twice daily (0330 and 1500 h) and milk yield of each milking was recorded (ALPRO, DeLaval, Tumba, Sweden).

The barn was equipped with a cooling system in the feeding area (3.2 m^2 per cow) consisting of axial fans (one per pen) and sprinklers. The airflow was directed along the feeding rail (longitudinal axis of the building). The fans (Ø 90 cm, 0.75 kW) had a maximum airflow rate of 22,500 m^3/h, were placed above the feeding area at approximately 2.5 m from the floor, and were angled downward at about 10° from vertical. The fans were controlled thermostatically and were switched on at 25.5 °C. The air speeds obtained in the feeding area with this system are shown in Table 1. A polyethylene pipe (diameter 5 cm) with four sprinklers spaced at 230 cm was placed above the feed barrier in each pen (each sprinkler covered a distance of 3 m). The sprinklers had a delivery rate of 5.5 L/min each, with a pressure of 150–200 kPa. A continuous spray was directed towards the feeding area, perpendicular to the airflow of the fans. The sprinklers were

Table 1 Air speed (m/s) measured longitudinally at 3, 6 and 9 m of distance from the fan in the feeding and in the resting area observed in the pen equipped with additional fans in the resting area

Longitudinal distance from the fan (m)	Height from the floor (m)	Lateral distance from the fan (m)			
		Feeding area		Resting area	
		0	1	0	1
3	1.0	0.61	0.85	0.68	0.40
	1.5	2.10	1.02	0.72	1.46
	2.0	3.55	1.27	1.06	3.50
6	1.0	1.51	2.40	3.22	1.13
	1.5	1.98	2.45	3.08	2.79
	2.0	2.44	3.11	3.53	3.36
9	1.0	2.65	2.13	0.55	0.45
	1.5	2.57	2.37	1.58	1.38
	2.0	3.14	2.84	1.68	1.87

controlled thermostatically and were activated at 28 °C and operated at increasingly more frequent intervals: 50 s of showering and ventilation followed by 10 min of only ventilation, with the time of only ventilation decreasing by 30 s for every degree over 28 °C. The free-stall area had straw bedding. The stall bed was made of separated manure solids and the straw was added twice a week, using 2.5 kg per free stall each time.

Experimental design

The 30 lactating cows involved in the trial were divided into two homogenous groups according to milk yield, calving number (2.43±1.35), and days in milk (150±47 day). One of the two groups was used as control (group CON) and these cows were kept in a pen without fans in the resting area (without forced ventilation of the free stalls). The cows in the other group (group FAN) were kept in a pen equipped with two fans (Ø 70 cm, 0.50 kW, maximum airflow rate of 15,000 m^3/h) positioned above the resting area, one per row of free stalls, to provide forced ventilation of the free stalls (Fig. 1). These fans were fixed at a height approximately 2.5 m from the floor and angled downward at about 10° from vertical, controlled thermostatically and switched on at 25.5 ° C (same as for feeding areas). The air speeds obtained in the free-stall area with this system are shown in Table 1.

Measurements

Microclimatic conditions

Air temperature and relative humidity inside of the barn were recorded using six electronic probes placed at animal height in different points of the two pens and a data logger programmed to record every 10 min (Gemini Data Logger, Chichester, UK). Mean, minimum and maximum daily values for air temperature and humidity were recorded throughout the trial. The data were used to compute a composite thermal comfort index, the temperature humidity index (THI), according to Kelly and Bond (1971), as reported by Ingraham et al. (1979). Mean, minimum and maximum daily values for THI were calculated throughout the trial and heat stress was estimated according to Armstrong (1994). According to the behaviour of the microclimatic conditions, four periods were identified during the summer season: P1 (15–30 June); P2

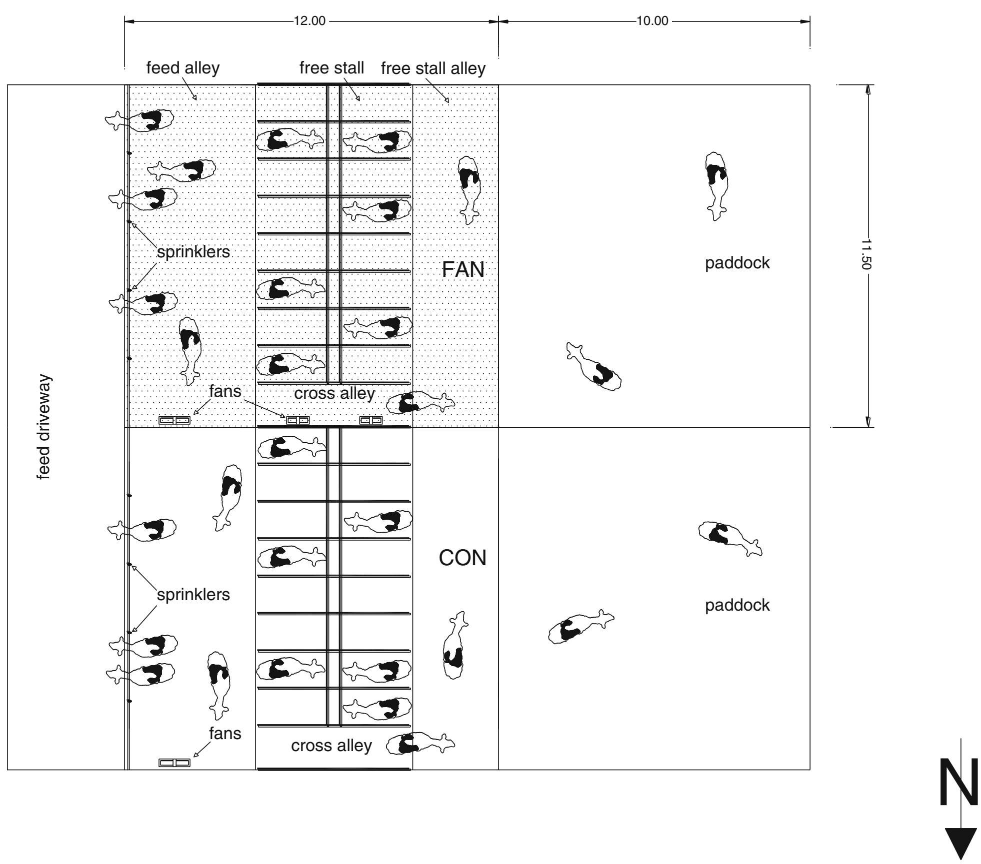

Fig. 1 Layout of the experimental barn

(1–15 July); P3 (16 July–3 August); P4 (4 August–15 September). The periods P2 and P3 were considered the hot periods, and P3 was the hottest period. During the hot periods the air speed in different points of each pen was also measured by manual probe (LSI, Milan, Italy). External temperature and relative humidity were also recorded during the trial.

Physiological variables

Rectal temperature and breathing rate were measured weekly on cows in the feeding area before milking (1500 h). For measurement of the rectal temperature a digital thermometer was used; an acoustic signal was emitted by the thermometer to signal when the probe was to be retracted from the rectum. The breathing rate of cows was registered by counting flank movements during two 30 s cycles.

Behaviour

Some normal behavioural routines of the cows (standing and lying in the different areas and animals in the feed bunk and in the paddock) were observed continuously from 1 July to 3 August by using a digital video camera on a revolving stand with a programmable intervalometer (one frame per second). The values were expressed in different time intervals: per hour and in intervals of 6 h (T1: from 0600 to 1200 h; T2: from 1200 to 1800 h; T3: from 1800 to 2400 h, and T4 from 2400 to 0600 h).

Milk yield, milk sampling and analysis

During the trial, the milk yield of each milking was recorded automatically daily (ALPRO, DeLaval). Representative individual milk samples were collected every week during the afternoon milking (one check point in P1; three in P2; four in P3; and two in P4). After sampling, milk samples were analysed immediately for pH using a pH meter, and titratable acidity (TA). The latter was measured by manual determination according to Alais (1984), where 50 mL milk sample was added to 100 μL phenolphthalein solution (1 % w/v in ethanol) and the mixture was titrated with standardised 0.25 M NaOH until the colour changed to pink.

Statistical analysis

Results were analysed using the MIXED models procedure (SAS Institute, Cary, NC) according to Littell et al. (1998). Sources of variation included treatment (two levels), period (two levels for the behavioural variables and four levels for rectal temperature, breathing rate, milk yield and milk characteristics), time (hours), and the interactions treatment x time, treatment x period, and treatment x period x time. The random variable was the day within period. The analysis was carried out using three covariance structures: autoregressive order 1, compound symmetry, and spatial power. These were ranked according to their Akaike and Schwarz Bayesian information criterion, and the covariance structure that fitted the model best was chosen according to Littell et al. (1998). Least squares means were computed, and pairwise comparisons (PDIFF option, SAS Institute) were conducted when the F-test of one of the main factors was significant at $P<0.10$. Statistical significance was designated as $P<0.05$ and tendencies were declared at $P<0.10$.

Linear regressions were developed from data collected only in hot periods (P2 and P3) by using each behavioral parameter as dependent variable and the daily max THI as the independent variable.

Results and discussion

Microclimatic conditions

The weather during the summer was normally hot, and microclimatic data evaluated during the trial are presented in Fig. 2. According to Armstrong (1994), heat stress in dairy cows is considered to be negligible when THI values are lower than 72. Index values higher than 72, 78 and 88 reflect the potential for mild, high and severe levels of heat stress, respectively. Based upon index values and on the recorded microclimatic conditions, the potential existed for dairy cows to suffer high heat stress for 52 days during the study period. During summer, the hot periods were observed in July (periods P2: 1–15 July; P3 16 July–3 August). During these hot periods, the daily minimum THI reached values near to the minimum value of the zone delimiting mild heat stress. Figure 2 shows that the heat stress was greater during P2 and achieved the maximum in the hottest period from the last week of July until the first days of August (P3), with daily minimum temperatures always above 20 °C. During P3, the mean daily temperature was on average 26.8±4.4 °C, greater than that observed during P2 (26.0±4.1 °C). During P2 a heat wave was observed (9–12 of July) and was classified, according to Hahn et al. (1999), as slight. During the hottest period (P3) a moderate heat wave was observed (22–25 of July).

As is usual in the area under consideration, high temperatures were associated with high relative humidity and limited air movement (Frazzi et al. 2000). The hourly average daily temperature during P2 and P3 (Fig. 3) shows that the maximum daily temperature was reached around 1800 h (31.8±2.1 °C and 33.5±2.8 °C in P2 and P3, respectively). The hourly average of relative humidity during P2 and P3 shows that the max daily humidity was reached around 0300 h (88.9±5.4 % and 86.4±8.7 % in P2 and P3, respectively). The daily behaviour of temperature and humidity results in achievement of the daily

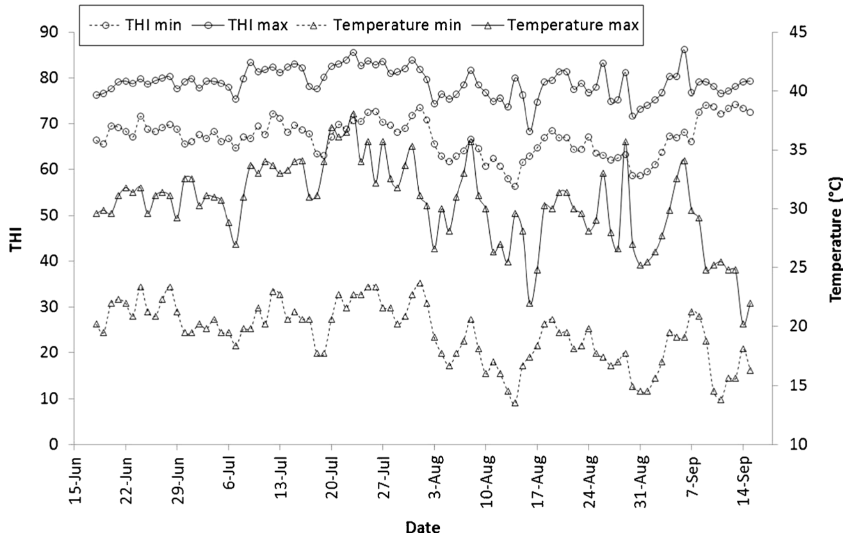

Fig. 2 Temperature (daily minimum and maximum) and temperature humidity index (THI; daily minimum and maximum) observed inside the barn during the trial

maximum THI around 1800 h (80.2±2.2 and 81.6±2.7 in P2 and P3, respectively). The behaviour of indoor daily temperature and humidity confirm our previous results (Frazzi et al. 2000 and 2002), and indicate that the microclimatic conditions were more unfavourable during late afternoon.

The air speed in the feeding area of the fan-cooled pen, observed at different heights from the floor (between 1 and 2 m) and at different longitudinal and lateral distances from the fan (Table 1), was on average 2.16±0.83 m/s (range 0.61 to 3.55 m/s). Air speeds lower than 1.0 m/s were observed only near the floor immediately below the fans. At a distance greater than 3 m from the fan, the air speed was always greater than 1.5 m/s. These data indicate that the air speed in the feeding area was on average greater than the critical speed of 2.04 m/s recommended by Chastain and Turner (1994).

The air speed observed in the resting area of CON pen was very low (on average 0.25 m/s). In the resting area of the FAN pen the air speed, observed at different heights from the floor (between 1 and 2 m) and at different longitudinal and lateral distances from the fan, was on average 1.80±1.14 m/s (range 0.40 to 3.53 m/s). On average the air speed in the resting area of FAN pen was below the minimal critical suggested by Chastain and Turner (1994), with high variability. An increase of the air speed above the values observed in the current study does not seems necessary because the benefit of increasing air speed is non-linear, and above 1.5 m/s the benefit seems very limited (Frazzi et al. 1998).

Physiological indices

The average rectal temperature always remained below 38.80 °C in each weekly check. During the hottest period (P3, end of July) the mean rectal temperature was 38.76 °C and 38.65 °C in CON and FAN treatment, respectively (Table 2), which was around the upper limit of the normal range of dairy cows (38.3–38.7 °C). Besides the effect of the conditioning system on thermoregulation, the acclimatisation of the cows to the hot conditions of the summer season could

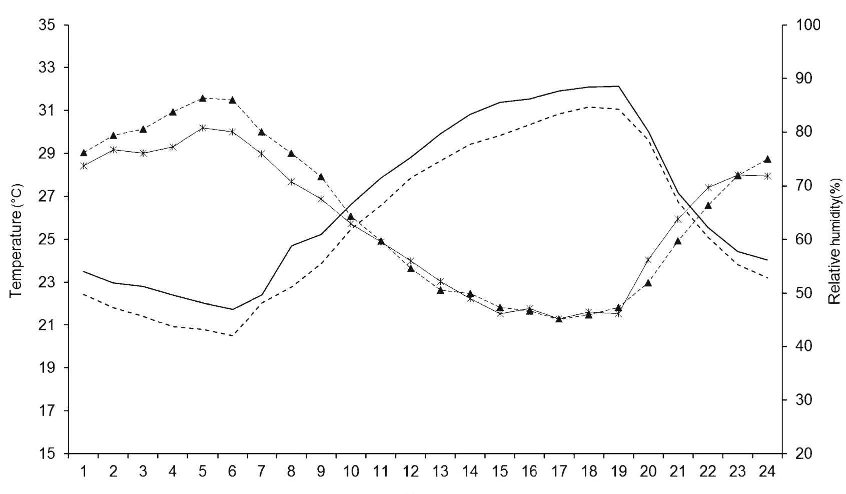

Fig. 3 Hourly average temperatures and relative humidity measured inside the barn during the hot periods. P2: 1–15 July (*dashed line* temperature; *dashed line and triangles* relative humidity); P3: hottest period 16 July–3 August (*continuous line* temperature; *continuous line and stars* relative humidity)

Table 2 Least square means of breathing rate and rectal temperature in cows during summer season and kept in pen without (CON) or with (FAN) fans in the resting area. *Tr* Treatment, *Pr* period

Item	Tr[a]	Pr[b]				SEM	*P* value		
		P1	P2	P3	P4		Tr	Tr x Pr	Pr
Breathing rate (n/min)	CON	58.4	56.2	57.0	53.0	1.860	ns	ns	0.034
	FAN	56.5	56.1	52.9	49.5	1.935			
Rectal Temperature (°C)	CON	38.8	38.8	38.8	38.8	0.051	ns	ns	ns
	FAN	38.8	38.7	38.6	38.7	0.054			

[a] CON: cows kept in pen equipped with fans and sprinklers in feeding area; FAN: cows kept in pen equipped with fans and sprinklers in the feeding area, and fans in the resting area

[b] P1: period 15–30 June; P2: period 1–15 July; P3: period 16 July–3 August; P4: period 4 August–15 September. The hotter periods were P2 and P3; P3 was the hottest period

largely explain these results, where the average rectal temperature was always below 39 °C in each measurement (Bernabucci et al. 2010). Furthermore, the hot conditions were not particularly severe and the measurement of rectal temperature was not carried out during the heat waves that occurred during P2 and P3.

To keep the body temperature within the range of thermoregulation, animals must increase heat loss and reduce the production of endogenous heat. Ventilation of the resting area provides good microclimatic conditions in the free stall during the hottest period, promoting heat dissipation for the cows kept in FAN pen. Breathing rate did not show particularly high values in either group, showing numerically greater values in CON compared with FAN cows. A significant effect of period was observed only in CON, with greater values observed during the first measurement (P1) performed after the first hot days of June (Fig. 2), indicating an acclimatisation of the cows to the hot conditions.

Milk yield

The milk yield level observed at first measurement was almost equal in both groups, and a reduction during the trial was observed in both groups (Table 3). On average, the reduction during the trial was 5.5 %/month. This reduction seems largely attributable to the advance of the days of lactation, taking into account the percentage of primiparous and the stage of lactation of cows considered in our trial (Casati et al. 1998). These results seem to indicate that the conditioning system in the feeding area attenuated the negative effect of hot conditions on milk yield. A numerically greater reduction was observed in CON (6.07 %/month) compared with FAN (4.93 %/month), with a greater reduction during the hottest period in CON (7.5 %/month) compared with FAN (5.3 %/month), when a difference of 1.0 L/cow per day between the two groups was observed. These results, although the differences were not significant, seem to indicate that the ventilation of the resting area allowed cows to maintain a better level of thermoregulation throughout the day, limiting the negative consequences of hot conditions on milk yield.

In the current study, the pH and milk titratable acidity were maintained around the optimal ranges, with no significant differences between periods and groups. Calamari and Mariani (1998) observed that milk produced during summer periods by cows raised in unfavourable climatic conditions, with high temperatures and humidity values, shows a worsening in the main cheesemaking characteristics. In particular, the reduction of the titratable acidity and the worsening of the rennet coagulation properties makes milk less suitable for the production of hard cheese with a long maturing time. Therefore, the maintenance of the level of acidity even in the hottest periods observed in the current study could be related to the heat stress not being particularly severe, and mainly to the attenuation of the impact of hot conditions obtained with the conditioning system adopted in the feeding area.

Behaviour

The statistical analysis of the data showed significant differences between P2 and P3 (only periods during which monitoring occurred) for all the behavioural parameters analysed. Just as significant were the effects of time (between data observed in intervals of 6 h during the day) and the interaction period x time for all the behavioural parameters (Table 4).

Normally in situations of even moderate heat stress, dairy cows tend to decrease feed intake to reduce body heat production and facilitate thermoregulation (West 2003). Thus, a reduction of eating time in heat-stressed cows could be expected, but in some trials the hot microclimatic conditions did not affect eating duration (Cook et al. 2007; Legrand et al. 2011). The time spent eating calculated from behavioral observations during P3 (Table 4) was on average 5.8 and 5.6 h/day in CON and FAN, respectively. These values are similar to data reported by DeVries et al. (2009) in high milking cows, and slightly higher than those

Table 3 Least square means of milk yield, pH and milk titratable acidity in cows during summer season and kept in pen without (CON) or with (FAN) fans in the resting area. Treatments and periods as in Table 2

Item	Tr	Period (Pr)				SEM	*P* value		
		P1	P2	P3	P4		Tr	Tr x Pr	Pr
Milk (kg/day)	CON	33.9	33.0	31.6	29.9	1.192	ns	0.096	0.0001
	FAN	33.8	33.4	32.4	30.1	1.145			
pH	CON	6.70	6.68	6.79	6.64	0.017	ns	ns	0.0001
	FAN	6.68	6.66	6.60	6.60	0.017			
Titratable acidity (°SH/50 ml)	CON	3.49	3.68	3.65	3.59	0.095	ns	ns	ns
	FAN	3.51	3.51	3.62	3.59	0.111			

of Cook et al. (2007). The high eating time observed during the hottest period in this study was encouraged mainly by the conditioning system adopted in the feeding area. The observed lack of differences between treatments could be expected, because the indoor microclimatic conditions were, in both pens, more favourable in the feeding area.

Among the main causes of increased daily standing time in modern dairy herds are heat stress behaviour, as well as poor stall design and comfort, overstocking, and prolonged milking times (Cook et al. 2007). In our study, the time spent standing indoors without feeding by the cows during P3 was on average 20.8 and 23 % of their time in CON and FAN, respectively

Table 4 Least squares means of lying and standing cows (%) inside and outside the barn during the hottest period[c]. Means with different letters are significantly different (a, b: $P<0.05$; A, B: $P<0.001$); The effects of period (P2 and P3), time and the interaction period per time, were significant ($P<0.05$) for all variables; the interaction of treatment per period, treatment per time and treatment per time per period were not significant. Treatments and periods as in Table 2

	Time[d]	Tr		SEM	Linear THI effect[e]	
		CON	FAN		CON	FAN
Lying in free stall	T1	51.09	53.11	2.777	−2.22** ±0.54	ns
	T2	48.05 a	50.86 b	1.644	ns	ns
	T3	29.74	30.07	2.075	−1.07** ±0.31	−1.73** ±0.54
	T4	15.34 a	24.75 b	4.399	−3.13* ±1.10	−2.80** ±0.78
Total standing[f]	T1	19.84	19.47	1.448	ns	−0.94* ±0.35
	T2	27.10	27.47	1.825	ns	ns
	T3	25.47 a	30.15 b	1.345	ns	ns
	T4	10.71 a	14.77 b	2.637	−1.97** ±0.51	−1.92** ±0.54
Standing[g]	T1	10.51	10.48	1.046	ns	−0.72* ±0.30
	T2	16.61	17.54	1.554	ns	ns
	T3	10.20 A	15.15 B	1.032	ns	ns
	T4	5.95	8.21	1.770	−1.55** ±0.37	−0.93* ±0.36
Paddock	T1	10.16	9.22	2.108	+1.37* ±0.55	+1.24* ±0.41
	T2	1.55	0.64	1.052	ns	ns
	T3	13.22 a	10.56 b	1.924	+1.51** ±0.39	ns
	T4	56.54 a	45.48 b	7.768	+6.16** ±1.67	+5.54** ±1.33

* $P<0.05$, ** $P<0.01$ (F probability of linear regressions)

[c] Hottest period was P3 (16 July–3 August)

[d] T1: data observed between 0000 and 0600 hours; T2: between 0600 and 1200 hours; T3: between 1200 and 1800 hours; T4: between 1800 and 2400 hours

[e] per unit of daily MAX THI. Calculated separately for cows kept in CON or FAN pen, and considering the hotter periods (P2: period from 01 till 15 July; and P3)

[f] Standing cows (excluding cows in feed bunk)

[g] Standing cows in free stall alley and cross alley

(Table 4). This means a time spent standing of 5.5 and 5.0 h/day in CON and FAN, respectively. These values are close to the data observed by Cook et al. (2007), where the microclimatic conditions were, however, characterised by a daily maximum THI lower than 63.5. Conversely, our standing time was always lower than the results obtained in the work of Cook et al. (2007) during hotter microclimatic conditions. The conditioning system adopted and the availability of an external area in our study could contribute to explaining the differences with the cited literature and also the differences between CON and FAN observed in this study.

The greater time spent standing without feeding in FAN compared with CON cows was significant in the afternoon, evening and late evening hours. These differences were not a consequence of differences of time spent standing in the feeding area, but were a consequence of significant differences observed for time spent standing in the resting area and for time spent outdoors (Table 4). These data suggest that the greater time spent standing in the resting area in FAN compared with CON cows in the afternoon hours was because the ventilation in the resting area, applied only in FAN, resulted in more favourable conditions for heat dissipation. During late evening the FAN cows found the indoor conditions favourable again because during the hottest period the ventilation system worked continuously through late evening and almost all night.

When a paddock is available, as in the current study, during hot conditions the cows spent more time outdoors during night hours, to benefit from external microclimatic conditions. On average, the time spent outdoors by the cows was 20.36 and 16.5 % of their time in CON and FAN, respectively. The largest presence of cows in the paddock was observed in late

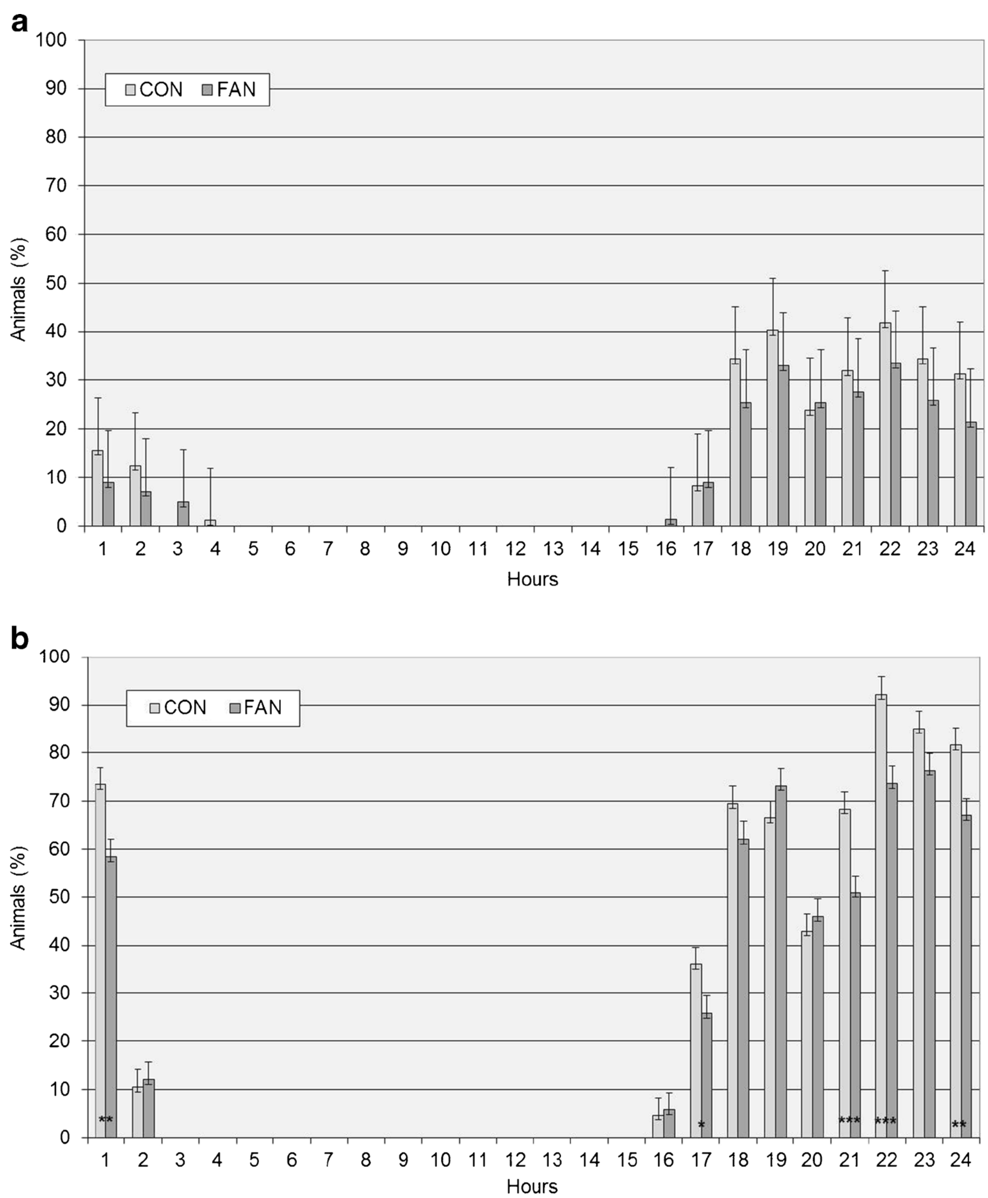

Fig. 4a,b Hourly average of animals in the paddock (as percentage of total cows in the pen) during the hot periods in cows kept in pens equipped with fans and sprinklers in feeding area (*empty bars* CON) and cows kept in pens equipped with fans and sprinklers in the feeding area, and fans in the resting area (*dark bars* FAN). *Vertical bars* SEM; *stars* significant differences (* $P<0.05$, **, $P<0.01$, *** $P<0.001$). **a** Values recorded 1–15 July (period P2), **b** values recorded during the hottest period (16 July–3 August, period P3) evening, with statistically significant greater values in CON compared with FAN. The analysis of data relating to the presence of animals in the paddock in the hot periods (P2 and P3), show in general low use of the paddock by both groups during period P2; conversely, during P3 values are considerably higher, especially for CON cows, with statistically significant differences, in particular at night (Fig. 4a,b). The linear regression with THI show a positive relationship between max daily THI and time spent outdoors during evening and late evening (Table 4). These results suggest that, during evening and late evening, a greater number of FAN cows found the resting area more comfortable than the external area. Conversely, CON cows at evening and during the night found the outdoor conditions more favourable and spent less time in the resting area and more time outdoors. In fact the average of daily minimum outside THI was lower (65.05 and 67.93 in the period P2 and P3, respectively), than the average daily minimum values observed inside the barn (66.71 in the P2 and 69.18 in the P3). Besides these differences, other benefits may attract animals outside (i.e. night breeze) during the night.

A negative effect of ambient temperature on the percentage of cows lying in stalls has been observed (Overton et al. 2002), and the time spent lying has been shown to be reduced in heat stressed cows (Frazzi et al. 2000). In the current study, the cows spent 36.0 and 39.7 % of their time lying in stalls in CON and FAN, respectively, which amounts to 9.5 h/day in CON and 8.6 h/day in FAN. These lying times are lower than the lying time of 12 to 13 h/day considered as the target resting period for healthy dairy cows (Cook et al. 2004; Jensen et al. 2005). The lying time observed in this study in CON cows coincides with the values observed by Cook et al. (2007)

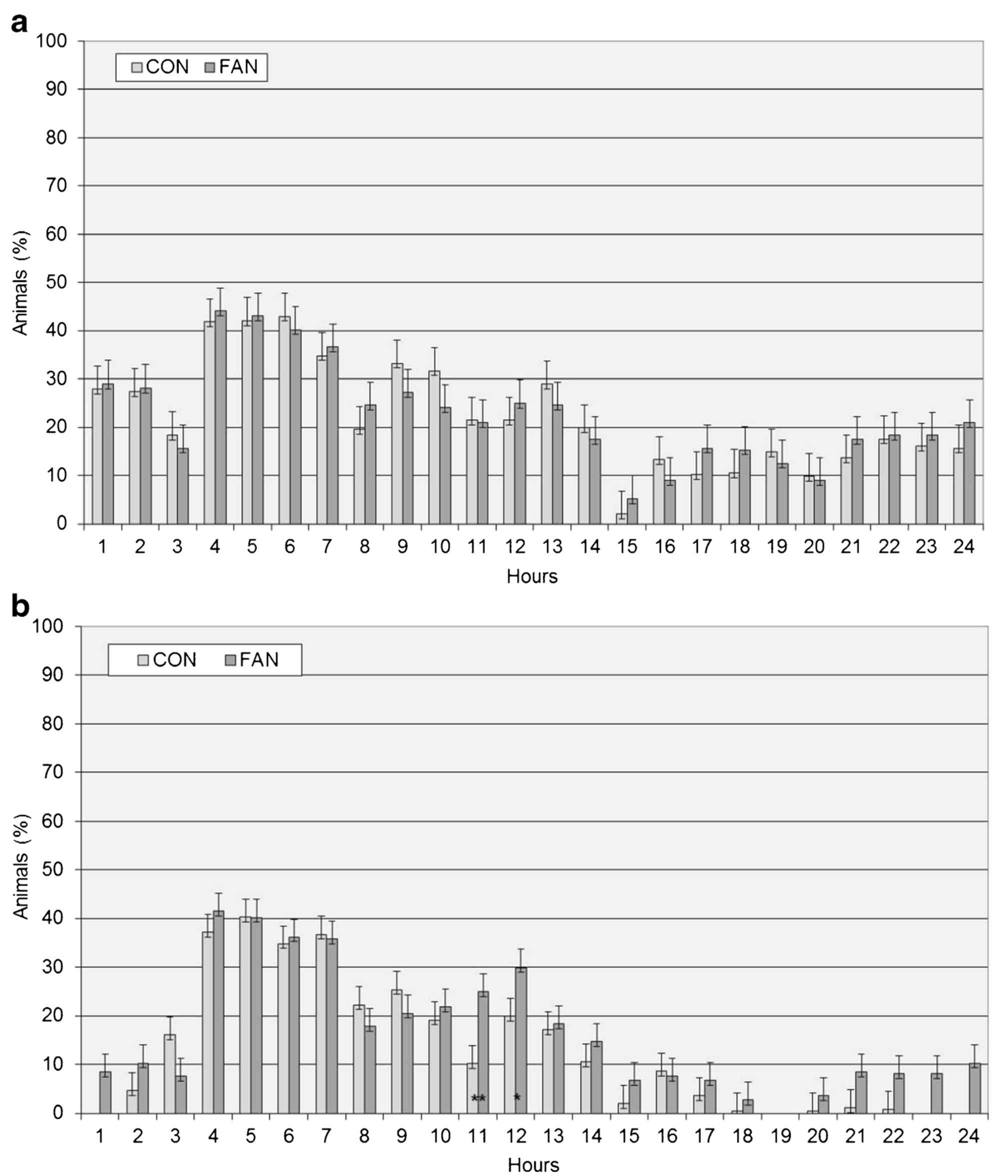

Fig. 5a,b Hourly average of animals lying in the external free stall row (as percentage of total cows in the pen) during the hot periods in cows kept in pens equipped with fans and sprinklers in feeding area (*empty bars* CON) and cows kept in pens equipped with fans and sprinklers in the feeding area, and fans in the resting area (*dark bars* FAN). *Vertical bars* SEM, *stars* significant differences (* $P<0.05$, ** $P<0.01$, *** $P<0.001$). **a** Values recorded 1–15 July (period P2), **b** values recorded during the hottest period (16 July–3 August, period P3) during the period with highest temperature-humidity index; conversely, the lying time observed in FAN cows was intermediate between the data observed by Cook et al. (2007) during periods with lowest and highest THI.

As in our study an external area was available to the cows in both pens, the total time spent lying has to take into account the time spent outdoors, mainly lying outdoors during evening and night. On average, the time spent outdoors during this trial was 4.9 h for CON cows and 3.8 h for those in FAN. Then, considering that, during this time the cows were mainly lying, the total lying time was close to 13.5 h/day in cows of both treatments, which can be considered close to an optimal value. Grant (2006) suggests a value up to 14 h/day for the most productive cows as optimal resting time, and recognised benefits include reduced stress on feet, reduced lameness, increased feeding activity, increased rumination activity and greater overall cow health. In our study, the CON cows in particular preferred the cooler outdoor climate at night, but we must remember that the paddock in dairy barns is often no longer available due to managerial, environmental and economic problems. Therefore, in order to maintain thermal comfort and resting time in the hot season, it is very important to keep the microclimatic conditions in the resting area comfortable.

During late evening, with a significantly greater presence of CON cows outdoors, a far lower value of lying cows was observed in CON cows compared to those in FAN. Conversely, the cows lying in the free stalls in the hottest hours of the day and in the morning time were similar in CON and FAN pens (Table 4). Spending time outdoors during the night allows the cows to benefit from external microclimatic conditions that are more favourable than the indoor conditions. This situation has been observed especially in cows of group CON; conversely,

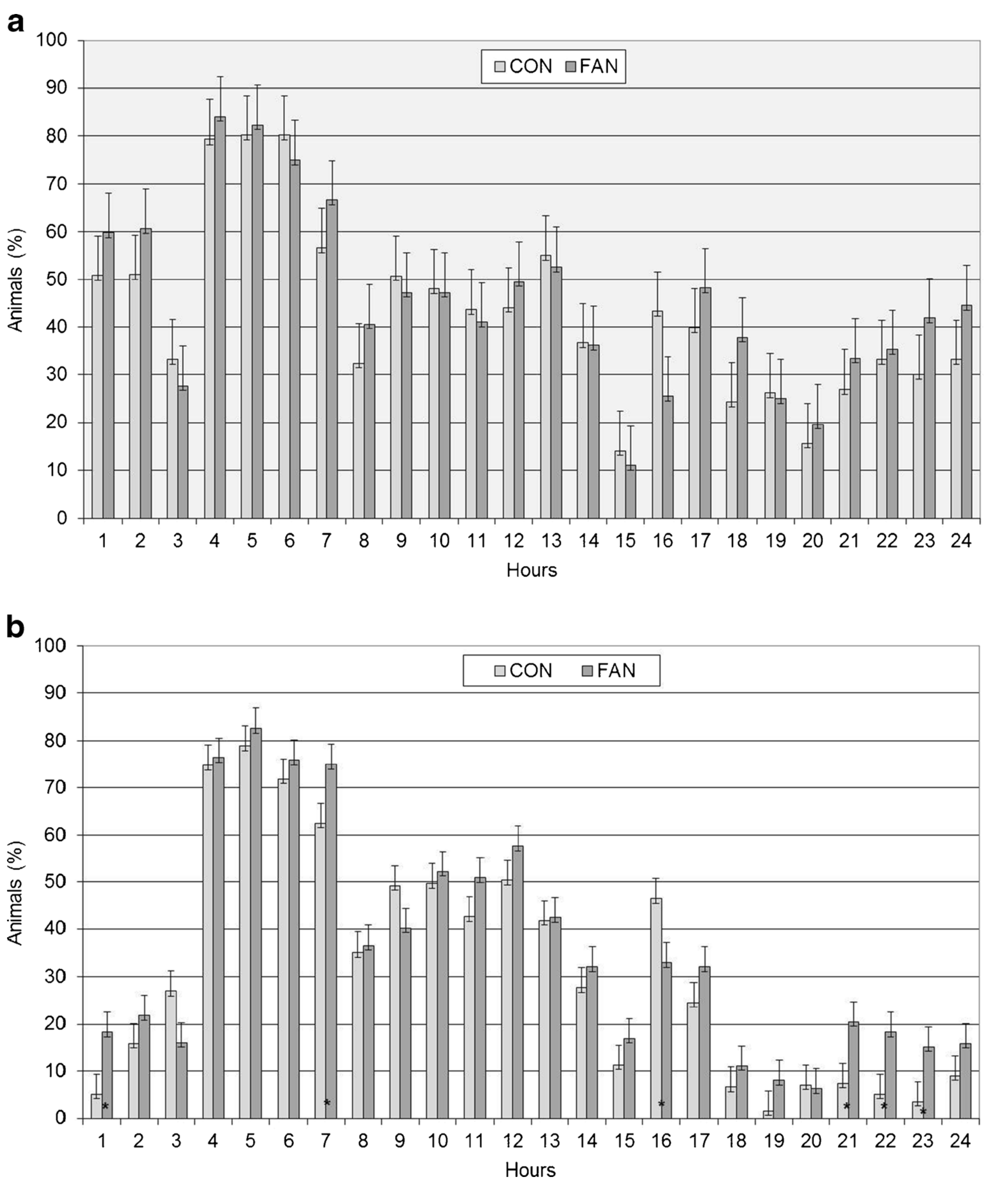

Fig. 6a,b Hourly average of animals lying in the free stall row (as percentage of total cows in the pen) during the hot periods in cows kept in pens equipped with fans and sprinklers in feeding area (*empty bars* CON) and cows kept in pens equipped with fans and sprinklers in the feeding area, and fans in the resting area (*dark bars* FAN). *Vertical bars* SEM, *stars* significant differences (* $P<0.05$, ** $P<0.01$, *** $P<0.001$). **a** Values recorded 1–15 July (period P2), **b** values recorded during the hottest period (16 July–3 August, period P3) most FAN cows preferred lying down in the resting area inside the barn even during the night, as a consequence of better thermal comfort in FAN compared to CON resting area, confirming our previous results (Calegari et al. 2012). Positive effects of adequate resting time, including greater overall cow health and welfare, were highlighted by Grant (2006) and Calamari et al. (2009). The positive effect of the ventilation in the resting area was particularly evident on the comfort of the free stall row by the free stall alley (west exposed) during the hottest periods. In fact, a great and significant reduction of lying cows in this free stall row in the afternoon and evening was observed during the hottest period (P3) compared with P2; this reduction was observed in particular in CON pen, and the number of lying animals during P3 was significantly lower in group CON compared with FAN. In this west exposed resting area, the sun's rays reached the external free stall row at 1600 h, causing a reduction in comfort from a microclimatic point of view. In FAN pen this negative effect was mitigated by forced ventilation (Fig. 5a,b).

During the hot periods (P2 and P3), we noticed a decrease in animals lying in both groups, with the lowest values in group CON with significant differences at night because a greater number of animals were lying in the paddock (Fig. 6a,b). A negative effect of daily max THI on lying time was observed during afternoon, evening and late evening in both treatments. Only in CON cows was the negative effect observed during the night. These results confirm the positive effect of the ventilation in the resting area, improving the comfort of the resting area and reducing the negative impact of hot conditions on lying time. The availability of a paddock provided an alternative to lying in an uncomfortable indoor resting area, which mitigated the negative effect on overall lying time.

Conclusions

The microclimatic conditions during the trial were characterised during the hot periods by some heat waves classified as slight-to-moderate heat stress. During these periods, the physiological markers of heat stress increased only slightly, either due to the positive effect of the cooling by surface adopted in the feeding area or as a consequence of the acclimatisation to the hot conditions of the summer season. The forced ventilation resulted only in a tendency to maintain milk yield during the hot periods.

The forced ventilation, however, resulted in significant changes in the behaviour of the cows, particularly in the use of the resting area within the barn and the external paddock available in this study. The results show greater use of the resting area in pens equipped with fans in the resting area compared to the control pen, and better distribution of animals inside the barn with greater use of the resting area. This indicates that providing fans in the resting area enhances dissipation of heat by cows.

In our study, the negative consequences of a hot resting area climate were mitigated because the paddock was available. A greater percentage of fan-cooled cows preferred to remain indoors during the evening and night, while a greater percentage of control cows preferred the cooler outdoor climate at night. The current trend in modern farms is not to use a paddock. In these cases, it is very useful to provide a climate conditioning system also for the resting area to make this area comfortable, thus allowing the cows to lie down and maintaining better welfare.

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