Original Article

Effect of Improved Cooling on Daily Rhythmicity of Body Temperature in Cross-bred Holstein Dairy Cows under Tropical Conditions

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Abstract

The objectives of this experiment were to study the effect of heat stress on daily rhythmicity of body temperature in dairy cows under hot and humid climatic conditions and to evaluate the efficacy of improved cooling system by monitoring body temperature. Sequential measurements of body temperature, air temperature, relative humidity and THI were monitored every 5 min. Four cross-bred Holstein-Frisian (93.75% HF) cows were assigned randomly to be used in two trial periods to determine the effects of heat stress and improved cooling system on body temperature. The experiment was conducted in the barn for a total of 6 days, 3 days without a supplemental cooling system (control) and 3 days with a supplemental cooling system (treatment). All cows were housed in the same barn throughout the experiment, but the treatment animals were exposed to the improved cooling system with sprinklers and fans in the holding pen 7 times a day. In this study, air temperature was negatively correlated (r = -0.983, p < 0.0001) with relative humidity, but positively correlated with THI (r = 0.996, p < 0.001). In addition, THI and air temperature were positively correlated (r = 0.709, p < 0.0001 and r = 0.714, p < 0.0001, respectively) with body temperature of the control animals. The mean level of body temperature of the control animals was higher (p < 0.05) than the treatment animals. Body temperature of the control animals consistently rose during the day, reaching a peak in the afternoon (1400 h), after which it remained relatively stable until midnight and then fell throughout early morning. The daily rhythmicity of body temperature had a mean level of 39.3±0.3^{0}C with a maximum-minimum range of 0.9^{0}C in the control animals. In contrast, body temperatures of the treatment animals fell by 0.3-1.0^{0}C after the improved cooling occurred at 0500, 0900, 1100, 1400, 1600, 1900 and 2200 h. Thus, their body temperatures were maintained in the range of 37.9-39.4^{0}C. The mean level of body temperature of these animals was 38.5±0.3^{0}C. In conclusion, climatic conditions have a significant influence on body temperature. Body temperature of dairy cows under tropical conditions has a daily rhythmicity, with a period of rising body temperature and increasing heat load during the day (hyperthermia), followed by a period of heat dissipation and falling body temperature during the night. Improved intensive cooling with sprinklers and fans has the potential to decrease the severity of heat stress and maintain a normal body temperature of dairy cows under hot and humid climatic conditions.

Keywords: cooling cow, cross-bred Holstein dairy cows, heat stress, rhythmicity of body temperature, tropical condition

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บทคัดย่อ

ผลกระทบของการเพิ่มการทำความเย็นต่อการเปลี่ยนแปลงของอุณหภูมิร่างกายในแม่โคนมพันธุ์ลูกผสมโฮลสไตน์ที่เลี้ยงในสภาพอากาศแบบร้อนชื้น

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การทดลองนี้มีวัตถุประสงค์เพื่อศึกษาผลกระทบของความเครียดจากความร้อนชื้นต่อการเปลี่ยนแปลงของอุณหภูมิร่างกายในรอบวันในแม่โคนมพันธุ์ลูกผสมโฮลสไตน์ที่เลี้ยงในสภาพอากาศแบบร้อนชื้น และเพื่อประเมินประสิทธิภาพของการเพิ่มระบบทำความเย็นโดยตรวจสอบจากการเปลี่ยนแปลงอุณหภูมิร่างกายของแม่โค โดยทำการตรวจวัดอุณหภูมิร่างกาย อุณหภูมิอากาศ ความชื้นสัมพัทธ์ และดัชนีวัดระดับความเครียดจากความร้อนชื้น (THI) ติดต่อกันทุก 5 นาที การศึกษานี้ใช้แม่โคนมพันธุ์ลูกผสมโฮลสไตน์-ฟรีเชี่ยน (93.75% HF) จำนวน 4 ตัว โดยแบ่งการทดลองเป็น 2 ช่วงเวลาๆละ 3 วัน คือ ช่วงเวลาที่แม่โคถูกเลี้ยงในคอกที่ไม่มีการเพิ่มระบบทำความเย็น (กลุ่มควบคุม) และช่วงเวลาที่แม่โคถูกเลี้ยงในคอกเดิมแต่มีการเพิ่มระบบทำความเย็นให้กับแม่โคโดยใช้ระบบหัวฉีดพ่นน้ำและพัดลมเป่าอากาศในคอกพักวันละ 7 ครั้ง (กลุ่มทดลอง) จากผลการศึกษาทดลองพบว่า อุณหภูมิอากาศมีความสัมพันธ์เชิงลบกับความชื้นสัมพัทธ์ (r = -0.983, $p < 0.0001$) และมีความสัมพันธ์เชิงบวกกับTHI (r = 0.996, $p < 0.0001$). นอกจากนั้น อุณหภูมิอากาศและTHI มีความสัมพันธ์สูงกับอุณหภูมิร่างกายของโคกลุ่มควบคุม (r = 0.714, $p < 0.0001$ และ r = 0.709, $p < 0.0001$ ตามลำดับ) โคกลุ่มควบคุมมีค่าเฉลี่ยของอุณหภูมิร่างกายสูงกว่ากลุ่มทดลองอย่างมีนัยสำคัญทางสถิติ ($p < 0.05$) การเปลี่ยนแปลงอุณหภูมิร่างกายของโคกลุ่มควบคุมในรอบวันนั้นมีการเปลี่ยนแปลงเพิ่มสูงขึ้นและลดลงทุกวัน โดยอุณหภูมิร่างกายมีระดับเพิ่มสูงขึ้นในช่วงเวลากลางวันและสูงสุดในช่วงเวลาบ่าย (14.00 น.) หลังจากนั้นอุณหภูมิร่างกายคงอยู่ในระดับสูงนานติดต่อกันจนถึงเวลาหลังเที่ยงคืนจึงมีระดับลดลงตลอดเวลาในช่วงเช้ามืด โคกลุ่มควบคุมมีอุณหภูมิร่างกายเฉลี่ย 39.3±0.3^{0}ซ. และมีช่วงห่างของอุณหภูมิสูงสุดและต่ำสุดเท่ากับ 0.9^{0}ซ. ส่วนอุณหภูมิร่างกายของโคกลุ่มทดลองนั้นมีการเปลี่ยนแปลงทุกครั้งหลังจากได้รับการทำความเย็นในช่วงเวลา 5.00 น. 9.00 น. 11.00 น. 14.00 น. 16.00 น. 19.00 น. และ 22.00 น. ซึ่งทำให้แม่โคมีอุณหภูมิร่างกายลดลง 0.3-1.0^{0}ซ. หลังจากทำความเย็น และทำให้แม่โคสามารถรักษาระดับการเปลี่ยนแปลงของอุณหภูมิร่างกายอยู่ในช่วง 37.9-39.4^{0}ซ. และมีค่าเฉลี่ยเท่ากับ 38.5±0.3^{0}ซ. จากการศึกษาทดลองนี้สรุปได้ว่า สภาพอากาศมีอิทธิพลต่ออุณหภูมิร่างกายอย่างมีนัยสำคัญทางสถิติ อุณหภูมิร่างกายของแม่โคนมที่เลี้ยงในสภาพอากาศแบบร้อนชื้นมีการเปลี่ยนแปลงตลอดเวลาทุกวัน โดยแม่โคจะมีอุณหภูมิและความร้อนสะสมในร่างกายเพิ่มสูงขึ้นในช่วงเวลากลางวัน หลังจากนั้นจะระบายความร้อนและอุณหภูมิร่างกายจะลดลงในช่วงเวลากลางคืน การเพิ่มระบบทำความเย็นให้กับแม่โคโดยใช้หัวฉีดพ่นน้ำและพัดลมเป่าอากาศในช่วงเวลาต่างๆทุกวันนั้นมีศักยภาพมากในการลดระดับความรุนแรงของความเครียดจากความร้อนชื้น ทำให้แม่โคนมที่เลี้ยงในสภาพอากาศแบบร้อนชื้นสามารถรักษาระดับการเปลี่ยนแปลงของอุณหภูมิร่างกายในรอบวันให้อยู่ในช่วงอุณหภูมิร่างกายปกติได้

คำสำคัญ: ทำความเย็นแม่โค แม่โคนมพันธุ์ลูกผสมโฮลสไตน์ ความเครียดจากความร้อนชื้น การเปลี่ยนแปลงอุณหภูมิร่างกาย สภาพอากาศแบบร้อนชื้น

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Introduction

Heat stress has a significant impact on dairy cattle in hot and humid climates. Environmental factors, which contribute to heat stress, include high air temperatures, radiant energy, and high humidity, all of which compromise the cow's ability to dissipate body heat. When cows cannot dissipate sufficient heat to maintain thermal balance, rectal temperatures greater than 39.0^{0}C and respiration rates greater than 60/min indicate that cows are undergoing heat stress sufficient to affect milk yield and fertility (Kadokawa et al., 2012). Air temperature is a major component of heat stress, however humidity must also be considered because evaporative heat loss is more effective when humidity is low. Temperature and humidity index (THI) combines temperature and humidity into an indicator of cow comfort. Cows begin to be stressed when THI exceeds 72, with moderate and severe heat stress occurring when THI is above 80 and 90, respectively (Armstrong, 1994). Increases in air temperature, THI, and body temperature above critical thresholds have been related to decrease feed intake and milk yield (Kadzere et al., 2002; West, 2003). In addition, heat stress can cause a decrease in fertility and represents a major factor of economic loss in dairy cows under hot and humid conditions (De Rensis and Scaramuzzi, 2003). These effects are the results of either hyperthermia associated with heat stress or physiological adjustments made by the heat-stressed animal to regulate body temperature (Hansen, 2009). Several methods have been used to improve dairy production in hot environments. Environmental modifications can alleviate severe heat stress in dairy cows to increase milk production and reproduction, such as sprinklers and fans and evaporative cooling systems (Avendano-Reyes et al., 2006; Urdaz et al., 2006; Suadsong et al., 2008; Chaiyaburt et al., 2008; Chanpongsang et al., 2010; Flamenbaum and Galon, 2010).

In hot and humid climatic conditions, dairy cows cannot dissipate sufficient body heat to prevent a rise in body temperature. In addition, metabolic heat increments require effective thermoregulatory mechanisms to maintain body temperature in a thermoneutral zone and in physiological homeostasis. Dairy cows can suffer hyperthermia if they fail to maintain thermoneutrality (Kadzere et al., 2002). The measurement of body temperature is a reliable method for the evaluation of heat stress in dairy cows. Vaginal temperatures were associated with rectal measurement, and provided the advantage of capturing diurnal changes in body temperature (Vickers et al., 2010). This is a relatively accurate tool for determining the degree of heat stress. In healthy dairy cows, a body temperature range from 37.9^{0}C to 39.6^{0}C for primiparous cows (mean 38.8^{0}C) and 37.9^{0}C to 39.5^{0}C for multiparous cows (mean 38.7^{0}C) was determined by Wenz et al. (2011). Daily rhythmicity of body temperature has a mean level of 38.3^{0}C, a range of excursion of 1.4^{0}C (Piccione et al., 2003). The daily rhythmicity of body temperature is influenced both by changes in heat production and changes in heat loss. Animals have a thermoregulatory system to regulate body temperature by balancing rate of heat exchange between the animal and its environment. Heat loss by conduction and convection is increased by lowering air temperature. Vickers et al. (2010) found that body temperature was higher at night, and lower between 0800 to 1000 h for healthy cows (39.0±0.02^{0}C). In tropical conditions, body temperature of dairy cows has been shown to decrease in cooled cows compared to non-cooled cows (38.7±0.5 and 39.7±0.6^{0}C, respectively). In addition, over a variation of environmental conditions, the body temperature of non-cooled cows was found to fluctuate from 38.9±0.7 to 39.7±0.6^{0}C (Chaiyabutr et al., 2008). However, sequential measurements of body temperature or daily rhythmicity in body temperature have not been studied in cross-bred Holstein dairy cows.

For dairy farms, farmers need information about how and why their animals respond to environmental challenges in order to make improved decisions on strategies and tactics for reducing losses during hot weather. These strategies involve minimizing heat gain by reducing solar heat load and maximizing heat loss by reducing air temperature around the animal or increasing evaporative heat loss directly from the animals. Measurements of body temperatures can be used to characterize stress levels of dairy cows and aid in further development of environmental modifications for improving their productivity. In addition, an understanding of the influences of climate change and the effectiveness of improved cooling systems on daily rhythmicity of their body temperature is necessary for control and management of dairy cattle housing. The objectives of this study were to examine the effect of heat stress on daily rhythmicity of body temperature in dairy cows under hot and humid climatic conditions and to evaluate the efficacy of utilizing an improved cooling system by monitoring internal body temperatures.

Materials and Methods

Experimental animals and management: This study was conducted in a commercial dairy farm that is located in the central part of Thailand. The experiment was performed in August, in which air temperature ranged from 25 to 33^{0}C and air humidity ranged from 60 to 80%. In this farm, lactating dairy cows were housed in a naturally ventilated free stall barn without a supplemental cooling system and were fed a total mixed ration (TMR) and water *ad libitum.* Dairy cows were milked twice daily (0200 and 1400 h).

The environmental management system for cooling cows in this study involved intermittent cooling with sprinklers and forced air ventilation with fans in the holding pen. Cows were cooled in the holding pen for 45 min with intervals of 2-3 hours between cooling periods, beginning at 0500 hours up to until 2200 hours. The cooling system during the cooling period (45 min) consisted of sprinklers and fans, sequentially activated to repeat cooling cycles of wetting by sprinklers for 1 min and air forced ventilation by fans for 4 min.

Four multiparous (2-3 lactations), cross-bred Holstein-Frisian (93.75% HF), healthy early postpartum (30-45 days) dairy cows were assigned randomly to use in two trial periods to determine the effect of this improved cooling system on body temperature. The experiment was conducted for a total of 6 days, 3 days each in the barn without the supplemental cooling system (control) and in the same barn with the supplemental cooling system (treatment). All cows were housed in the same barn throughout the experiment, but treatment animals were exposed to the improved cooling system with sprinklers and fans in the holding pen 7 times a day at 0500, 0900, 1100, 1400, 1600, 1900 and 2200 hours.

Data collection

Environmental conditions: Environmental conditions in the barn such as air temperature and relative humidity were recorded every 5 min using data loggers (Easy log®, EL-USB-2; Lascar Electronics, Salisbury, UK) throughout the experiment. The temperature humidity index (THI) was calculated according to the formula: THI = (0.8 x T) + [(RH÷100) x (T-14.3)] + 46.4 where T was air ambient temperature (^{0}C) and RH was relative humidity (%) (Gaughan et al., 2010). Mean level of air temperature, relative humidity and THI were calculated for 5-min blocks.

Cow temperature: A more comprehensive assessment of body temperature throughout the day was obtained by the use of a small computerized data logger attached to a blank CIDR device. The data logger (Thermocron®, iButton; Maxim, Sunnyvale, California, USA) was used in this study to monitor internal body temperature every 5 min. It was designed to continuously monitor the animal's body temperature 24 hours a day. These devices were inserted into the vagina of the dairy cows. Vaginal temperatures were recorded for all cows in this study (both those exposed to and those not exposed to the supplemental cooling system) throughout the day to determine the daily rhythmicity in body temperature.

Statistical analysis: Sequential measurements of body temperature, air temperature, relative humidity and THI were monitored every 5 min. The level of mean was calculated for 5-min blocks throughout a day. Data were presented as mean±SD. Significant difference of each parameter between groups was tested by *t*-tests for matched samples by repeated-measures analyses of variance (ANOVA). Relationships between parameters were examined by simple correlation. The level of significance was set at $p < 0.05$.

Results

Environmental conditions: Climatic conditions in the barn (air temperature, relative humidity and THI) were plotted as a function of time of day in Figure 1. Each data point represented the mean air temperature, mean relative humidity and mean THI for a given 5-min interval throughout a day. The mean air temperature over the experiment was 29.3±2.3^{0}C. Air temperature consistently rose during the day, reaching a maximum air temperature of 33.1^{0}C in the afternoon (1300 h). It remained stable until the evening and then fell throughout the night. The minimum air temperature was 26.1^{0}C and occurred at 0600 h. In contrast, relative humidity rose during the night, reaching a peak in the morning. The maximum relative humidity was 86.1%, which occurred at 0600 h, after this it fell during the day. The minimum relative humidity was 62.3% which occurred in the afternoon (1500 h). The mean relative humidity was 74.5±8.0%. In this study, air temperature was negatively correlated (r = -0.983, p < 0.0001) with relative humidity, but positively correlated with THI (r = 0.996, p < 0.0001). The mean THI in the barn was 80.6±2.3. The maximum THI was 84.6 and occurred in the afternoon (1300 h) and fell throughout the night. The minimum THI was 77.3 and occurred at 0600 h. In this study, THI exceeded the critical point of 72 throughout the experiment. The exposure to condition of severe heat stress (THI > 80) occurred in late morning through late evening. The condition of mild heat stress occurred in early morning. In addition, THI and air temperature were positively correlated (r = 0.709, p < 0.0001 and r = 0.714, p < 0.0001, respectively) with body temperature in the control animals. These results indicate that climatic conditions have a significant influence on body temperature of dairy cows in hot environments.

Cow temperature: The mean vaginal temperatures of four dairy cows were measured both with and without supplemental cooling system exposure. Internal body temperatures plotted as a mean of vaginal temperature of each 5-min interval for each trial period (control and treatment) are shown in Fig 2. The mean vaginal temperature of the animals without supplemental cooling system (control) was higher (p < 0.05) than the treatment animals. Body temperatures rose during the day and fell gradually during the night, reaching a daily low level early in the morning. The mean level of body temperature was 39.3±0.3^{0}C for the control animals and 38.5±0.3^{0}C for the treatment animals. The maximum and minimum of body temperature were 39.7 and 38.8^{0}C, respectively for the control animals, and 39.4 and 37.9^{0}C, respectively for the treatment animals.

In the control animals, body temperature consistently rose during the day, reaching a peak in the afternoon (1400 h) and then remained relatively stable until midnight after which it fell throughout the

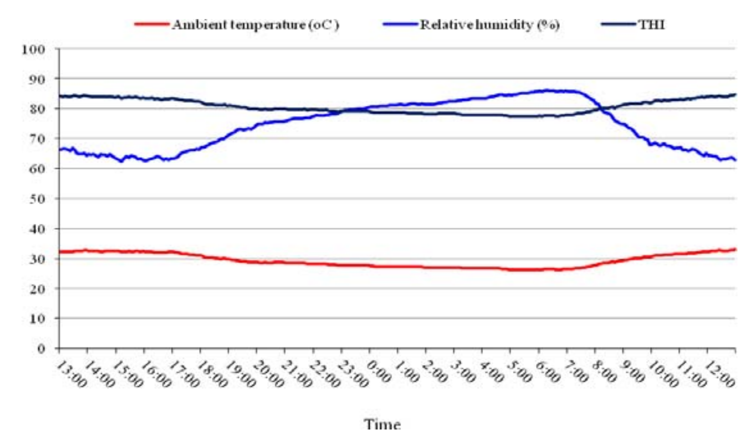

Figure 1 Daily changes in mean of air temperature, relative humidity and THI in the dairy farm barn throughout the experiment.

early morning. In contrast, the mean of body temperatures of the treatment animals fell by 0.3-1.0^{0}C after the improved cooling occurred at 0500, 0900, 1100, 1400, 1600, 1900 and 2200 h, thus maintaining the body temperature of the cows in the range of 37.9-39.4^{0}C.

A regular pattern of daily rhythmicity of body temperature occurred in both groups; however there was significant difference between the groups. In the control animals, the body temperatures rose during the day. Minimum body temperature usually occurred early in the morning (0600 h), and then steadily increased during the day. Maximum body temperature usually occurred in the afternoon (1400 h). The heat load built up during the day was dissipated at night such that body temperature fell gradually during the night, reaching a daily low level early in the morning. The daily rise in body temperature and sustained hyperthermia for long periods did not occur in the treatment animals. The body temperatures of the treatment animals slowly increased during the day and fell after cooling in the holding pen, and then steadily increased when the animals were out of the barn. However, the body temperature fell markedly when these animals returned to the holding pen again.

Discussion

As can be seen from the climatic conditions shown in Fig 1, the dairy cows in this study were subjected to moderate heat stress during the day and mild heat stress during the night throughout the experiment. A comfortable environmental temperature range for dairy cows is between 4^{0}C and 25^{0}C (Roenfeldt, 1998), but the climatic conditions in the central part of Thailand generally involve high temperature and high relative humidity throughout a year. Thus, heat stress is chronic in nature; there is often little relief from heat during the night until early morning. Increase in air temperature above 27^{0}C causes elevation of body temperature, which is defined as hyperthermia in cattle (García-Isperito et al., 2007). In this study it was found that air temperature and THI were highly correlated with body temperature in the dairy cows without a supplemental cooling system. These cows had a high body temperature during a significant portion of the day and their body temperature returned to normal only during late night and early morning (Fig 3). Maia et al. (2005) reported that when air temperature was greater than 30^{0}C, cutaneous evaporation became the primary venue for heat loss, accounting for approximately 85% of the total heat loss, while the rest was lost by respiratory evaporation. In this study, the control cows generally needed several hours past sundown to dissipate heat and cool down from an extremely hot day. The increase in body temperature is a normal mechanism by which animals respond to the heat load from hot ambient conditions and the heat loss by convection and evaporation is effective only when the air temperature declines below 27^{0}C, not under high environmental air temperature and air humidity during early night. Heat flow occurs through processes dependent on surrounding temperature and humidity. Hansen (2004) reported that heat loss by skin was dependent on the temperature gradient between the animal and the air. Burfeind et al. (2012) reported that during the hot period (THI 74.1±4.4), healthy dairy cows exhibited rectal temperature ≥ 39.5^{0}C. Therefore, in order to minimize the effects of heat stress, modifications to dairy housing environments have been implemented to alleviate thermal stressors and improve cow comfort. In addition, a cow's body temperature should be maintained within narrow limits in order to sustain its physiological processes. A variety of cooling systems are available for heat-stressed cows to maintain normal body temperature during the day (Flamenbaum and Galon, 2010). Intensive cooling systems with a combination of sprinklers and fans have been used for improving cow comfort, milk yield

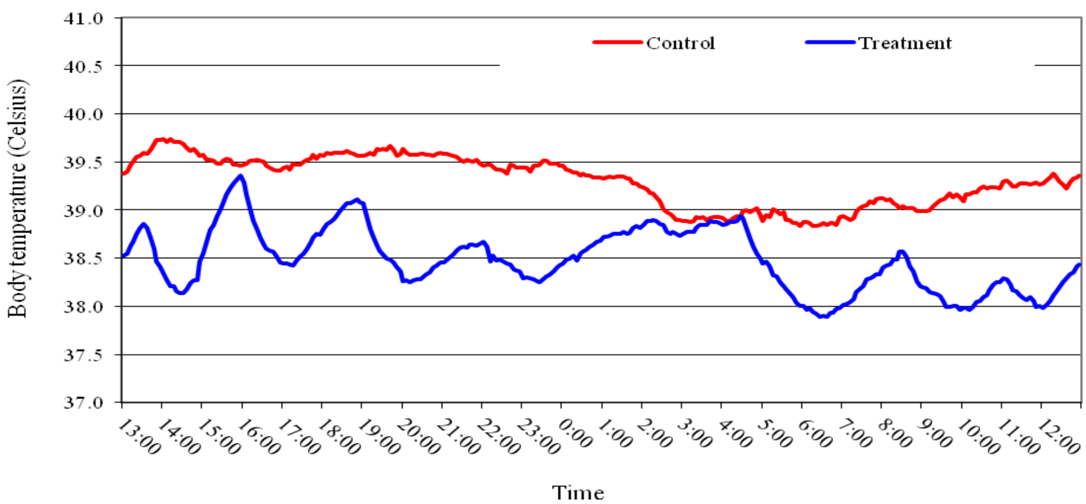

Figure 2 Daily changes in mean vaginal temperatures of control (cows without supplemental cooling system) and treatment (cows with supplemental cooling system) animals throughout the day

and reproduction (Collier et al., 2006; Flamenbaum and Galon, 2010). This system enhanced the conductance of heat from the body core to the skin by wetting of skin and from skin to the surrounding air by air forced ventilation. Gebremedhin et al. (2008) reported that wetting the skin surface and increasing air velocity profoundly increased evaporation rate by converting sensible heat to latent heat. The average body temperature of cooled cows in this study was most likely 38.5^{0}C. According to this study, the range was found to be 37.9 to 39.4^{0}C, and the proportion of hourly body temperature values above the threshold (> 39.0^{0}C) was also lesser in the treatment cows compared with the control cows. These results suggest that the supplemental cooling in the holding pen for 7 times per day was effective in reducing body temperature of cross-bred Holstein dairy cows.

The dynamic responses of body temperature to environmental conditions shown in this study demonstrate the utility of environmental management. Environmental temperature had a significant influence on the body temperature of cross-bred Holstein dairy cows. Body temperatures of these cows in hot and humid conditions tend to increase during daylight hours, and then heat load is dissipated at night. The intensive cooling system used in this study had a significant effect on the decrease in body temperature and allowed the cows to maintain a normal body temperature of 38.5-39.3^{0}C relatively easily throughout a day. As shown in Fig 2, the mean level of body temperature of the control animals was consistently higher than the body temperature in treatment animals. In addition, the duration of hyperthermia in the control animals was longer than in the treatment animals. Heat stress increases the body temperature of dairy cow which affects the reproductive functioning and production. Dry matter intake and milk yield can decrease about 20-25% in cows subjected to heat stress under tropical conditions (Suadsong et al., 2008; Chanpongsang et. al., 2010). Previous research indicates that improved cooling systems for cross-bred Holstein dairy cows under hot and humid climatic conditions results in decreased body temperature and increased feed intake and milk production (Chaiyabutr et al., 2008; Suadsong et al., 2008). In addition, heat stress can cause infertility and represents a major source of economic loss in dairy cows under tropical conditions. High air temperature causes a significant reduction in fertility in cattle. Hyperthermia leads to disturbances in the functioning of the reproductive system (Rynkowska et al., 2011). Paula-Lopes et al. (2012) reported that exposure of bovine oocytes to elevated temperature affected the events required for successful oocyte maturation, fertilization and preimplantation embryonic development. The elevation of temperature decreasing oocyte function occurs due to a series of cellular alterations that affects nuclear and cytoplasmic compartments of the bovine oocyte. Previous research reported that the reproductive dysfunction caused by heat stress could be reduced by reducing the magnitude of heat stress that drove dairy cows into hyperthermia (Hansen and Arechiga, 1999). It's difficult for dairy cows in hot environments to meet their full potential for either milk yield or fertility. The most common way to reduce the effects of heat stress on dairy cow is to change the cow's environment to reduce the severity of heat stress. Therefore, the study of the daily rhythmicity of cow's body temperature can increase the effectiveness of heat stress management by providing information as to how well cows regulate body temperature during the day.

In conclusion, in this study, climatic conditions were shown to have a significant influence on body temperature in cross-bred Holstein dairy cows under tropical conditions. Body temperature was found to have a daily rhythmicity in which there was a period of rising body temperature and increasing heat load or hyperthermia during the day, followed by a period of heat dissipation and falling body temperature during the night. The improved cooling system was shown to have the potential to decrease the severity of heat stress and to help maintain a normal body temperature in cross-bred Holstein dairy cows. Consequently, this study is particularly useful for the development of proactive tactical management guidelines for dairy cattle producers in tropical areas.

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