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ORIGINAL ARTICLE

# Application of a tunnel-ventilated barn on the physiological responses, milk yield, and dry matter intake of dairy cows in tropical area during the wet season

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**Abstract** Dairy cows often experience heat stress in the tropics. Tunnel ventilation technology reduces heat stress in dairy cow housing. Here, we examined the performance of tunnel-ventilated barns on the physiological responses, milk yield, and dry matter intake of dairy cows during the wet season in a tropical area. The experiment was conducted on a commercial dairy farm in Malang, Indonesia from mid December 2017 until mid January 2018. Lactating Friesian Holstein cows (n = 661) were studied in two barns of different dimension, with cooling treatments. Air temperature, relative humidity, and air speed were measured. Respiration rate, lying down percentage, milk yield, and dry matter intake were analyzed in response to modified environmental conditions. Data were analyzed with independent sample *t* tests using SPSS® Statistics 24 for Windows. Outisde and inside air speeds for both barns ($P < 0.05$) showed significant difference. Surprisingly, no differences were found for temperature (T), relative humidity (RH), and temperature–humidity index (THI) between the outside and inside for both barns ($P > 0.05$). A significant difference was noted in milk yield, dry matter intake (DMI), respiration rate (RR), and lying down percentage (LDP) ($P < 0.05$). Thus, the tunnel-ventilated barn performed better and air speed was better distributed inside the barn. However, the barn had environmental conditions similar to those outside. Dairy cows showed high RR as milk yield and DMI increased. In the future, lying down behavior of dairy cows in response to cooling treatments in the tropics needs to be further studied.

**Keywords**: dairy housing, heat stress, tropical environment

## Introduction

High temperature and air humidity are the main constraints for maintaining dairy cows in tropical areas (Gantner et al 2011; Palulungan et al 2013). Typically, temperature (T) and relative humidity (RH) in tropical areas range from 24 to 34°C and 60 to 90%, respectively. However, the dairy cow thermoneutral zone ranges from 13 to 25°C. In a tropical environment, even in the wet season, dairy cows still potentially experience continuous heat stress resulting in decreased productivity (Yani and Purwanto 2006).

The temperature–humidity index (THI) is widely used to indicate cow heat stress but is designed for a dry environment (Armstrong 1994; Ravagnolo et al 2000). Milk production decreased by 0.32 kg per unit of THI increase (West 2003) and by 0.2 kg per unit THI when THI exceeded 72 (Ravagnolo et al 2000). Additionally, air speed and solar radiation and their interactions are environmental contributors of heat stress (West 2003). Physical modification of the environment can reduce the effects of thermal stress (Beede and Collier 1986); shading, housing, and fans are techniques used to alleviate the impacts of heat stress on dairy cattle (Panjono et al 2009).

Tunnel ventilation technology facilitates the reduction of heat stress for housed dairy cows (Smith et al 2006a). Tunnel ventilation systems are designed to achieve a specific air speed to optimize convective heat loss by placing a bank of fans at one end of the building with inlets at the opposite end (Shiao et al 2011). Previous studies have reported that cows produced 3% more milk at the tunnel-ventilated barn than in a conventional free-stall barn in a subtropical area (Shiao et al 2011). There was also an increase in milk yield over a 10 week trial by 2.8 ± 0.19 kg/cow day$^{-1}$ in a temperate zone (Smith et al 2006b). This study examined the effects of tunnel-ventilated barn on the physiological responses, milk yield, and dry matter intake of dairy cows during the wet season of a tropical area. We hypothesized that there would be a difference in milk yield, dry matter intake (DMI), and physiological responses between the two barns and between temperature (T), relative humidity (RH), and air speed outside and inside the barn.

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## Materials and Methods

The experiment was conducted on a commercial dairy farm in Malang (latitude 07°46'48"-08°46'42" S and longitude 112°31'42"-112°48'48" E), Indonesia from mid December 2017 until mid January 2018 during wet season. The rainfall average from December until January was 268 mm (*Badan Pusat Statistik* (BPS), Central Bureau of Statistics Indonesia 2017). The wet season is categorized by rainfall exceeding 100 mm in one month (As-syakur 2008).

A total of two barn cooling treatments were established. The control barn (BC) had a maximum roof height of 4.85 m, side eaves of 3.65 m, and a total area of 154 m × 30 m. The treatment barn (BT) had a maximum roof height of 8.3 m, side eaves of 4.9 m, and a total area of 158 m × 30 m. Both barns were open at the front. A total of 31 (BC) and 46 (BT) exhaust fans (15 horse power, 1.4 m diameter, 3 blades), were placed at the back of each barn, and were operated for 24 h/d and were covered by a segmental plastic curtain. The pen floors were made of iron segmental lining for pen and the alley was made of concrete. A light was turned on for 12 h during the night. The cow allocation area (117.3 m long × 4.6 m wide for BC; 120 m long × 4.6 m wide for BT) was horizontally divided into 2 equal-sized pens in each barn (pen A and B). The space between the two pens was 4.9 m long × 4.6 m wide. All of the facilities, including the stalls, water and salt trough, headlock, and the floor plan of the two experimental barns were similar.

All animal use protocols for the exploratory research was reviewed and approved by the commercial dairy farm. A total of 661 lactating Friesian Holstein (FH) cows were divided in 2 groups based on their days in milk (DIM). Their average condition before the trial but during the wet season was 11.2±0.83 for pen A of the BC barn, 42.6±2.88 for pen B of the BC barn, 105.8±1.92 for pen A of the BT barn, and 114.6±4.56 for pen B of the BT barn. Every day, cows were moved from other barns (first-lactation cow) to the BC, the BT and other barns based on DIM. Cow population constantly changed in the barn pens because of the different DIM. Thus, to calculate the results, cow sample size was determined by using the smallest population during the research period.

During the 31 day trial period, sample data were taken every 2 days, and barn T, RH, and air speed were measured every 3 h for 24 h both inside and outside of each barn. T and RH were measured using 6 hygrothermographs (Xuzhou Sanhe Automatic Control Equipment Co., Ltd., China) that were consistently spaced in 3 locations above the headlock and stall positions, 2.5 m above the ground in each barn. The outside T and RH were measured at the south and north points of each barn. To plot the diurnal changes and to calculate THI, temperature and RH for each barn was first averaged by time and the number of data points and was then averaged across the number of days [THI = 9/5 × T + 32 - 0.55 × (1 - RH) × (9/5 × T - 26), with T in °C and RH in percent] (NOAA 1976). In this study, THI was categorized based on Hahn et al (2009). Air speed measurements were collected similar to T and RH using Lutron LM-8000A (ISO 9001 Quality Management System Certified by SGS).

During the experiment, individual cow respiration rate (RR) was counted five times during a 24 h period since cows were inside the barns at 0300, 0900, 1200, 1800, and 2100. Respiration rate was measured by flank movement per minute and was counted for 15 s (Ortiz et al 2015). Lying down percentage (LDP) was measured similar by first counting the number of standing cows then the number of eating and drinking cows. To calculate the number of lying down cows, the number of standing cows and eating and drinking cows were subtracted from the total number of cows. The LDP was calculated by dividing the number of lying down cows with the number of standing and lying down cows (excluding the eating and drinking cows) and then multiplying the quotient by 100 to calculate the percentage.

$$\text{LDP}=\frac{\text{lying down cows}}{\textit{laying down cows} + (\textit{standing cows} - \textit{eating and drinking cows})}\ x\ 100\%$$

The measurement of other physiological responses, including heart rate, rectal temperature, and pulse rate, were prohibited by the management board of the commercial dairy industry to avoid animal discomfort.

Feed samples for lactating cows were collected at 3 different locations (the front, middle, and rear of the feed line) of the BC and BT barns and were then mixed thoroughly before undergoing 48 h of drying at 55°C. Dried feed samples were pooled, ground, and analyzed. The cows were fed a total mixed ration (TMR) *ad libitum* on the feed line and were allowed continuous access to water. The TMR was composed of alfalfa hay and concentrate. The mean chemical composition of the TMR was 11.89 Mcal of $NE_L$/kg, 16.29% crude protein and 5.17% crude fat (DM basis).

The amount of TMR offered, next-day refusals, and the actual number of cows in each group were recorded daily. Fresh TMR and next-day refusals were sampled daily for two weeks from the 0-d trial date to determine the dry matter intake (DMI) measurement per pen. Cows were milked thrice daily at 0600, 1400, and 2200. Individual milk yields were recorded on a daily basis and were averaged by pen.

Relative environmental measures were expressed as the mean ± standard mean error. Bovine data, including RR, LDP, milk yield, and DMI were analyzed by each group. Data were analyzed using IBM® SPSS Statistics 24.0 for Windows. Independent sample *t* tests were used to compare the cooling effect between the two barns at a significance level of P<0.05. If the P-value was close to 0.01, the presence of a tendency was noted.

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## Results

There was a significant difference in the air speed between the outside and inside for both barns (P < 0.05). However, no differences were found for T, RH, and THI between outside and inside for both barns (P > 0.05) (Table 1).

For this study, the cows were only out of the barn for milking. Thus, we compared LDP and RR of the cows for the BC and the BT barns. There was a significant difference in milk yield, DMI, RR, and LDP (P < 0.05).

**Table 1** Mean values of environmental conditions of the tunnel-ventilated barn for 24 h.

| BC Barn | | Time (h) | | | | | | | | | Mean | SEM± | P value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0000 | 0300 | 0600 | 0900 | 1200 | 1500 | 1800 | 2100 | 2400 | | | |
| Temperature (°C) | In | 20.14 | 19.27 | 20.06 | 22.91 | 23.81 | 22.14 | 20.72 | 19.99 | 20.15 | 21.26 | 0.18 | $0.07^{ns}$ |
| | Out | 20.09 | 19.50 | 20.4 | 25.61 | 26.40 | 22.14 | 20.80 | 20.40 | 20.10 | 21.89 | 0.30 | |
| Relative humidity (%) | In | 87.60 | 89.33 | 88.89 | 83.72 | 83.78 | 89.94 | 93.72 | 88.61 | 87.83 | 85.64 | 1.33 | $0.80^{ns}$ |
| | Out | 89.21 | 89.30 | 88.00 | 83.30 | 76.90 | 84.90 | 92.70 | 84.60 | 89.20 | 86.10 | 1.24 | |
| THI | In | 67.30 | 66.29 | 67.55 | 71.83 | 73.32 | 70.99 | 68.88 | 67.36 | 67.36 | 69.41 | 0.32 | $0.13^{ns}$ |
| | Out | 67.41 | 66.50 | 68.10 | 76.16 | 76.70 | 70.54 | 68.90 | 67.80 | 67.50 | 70.27 | 0.46 | |
| Air speed (m/s) | In | 2.39 | 2.65 | 2.87 | 2.38 | 2.19 | 2.26 | 2.20 | 2.18 | 2.65 | 2.56 | 0.06 | 0.00* |
| | Out | 1.01 | 0.48 | 0.68 | 1.89 | 2.45 | 1.75 | 1.28 | 1.51 | 1.65 | 1.46 | 0.16 | |
| BT Barn | | | | | | | | | | | | | |
| Temperature (°C) | In | 19.90 | 19.71 | 20.51 | 23.48 | 24.22 | 21.95 | 20.71 | 20.26 | 19.98 | 21.67 | 0.21 | $0.87^{ns}$ |
| | Out | 20.08 | 19.50 | 20.50 | 24.83 | 25.00 | 22.25 | 20.60 | 20.40 | 20.10 | 21.62 | 0.25 | |
| Relative humidity (%) | In | 89.20 | 92.06 | 87.72 | 83.56 | 79.72 | 91.67 | 94.77 | 89.72 | 89.27 | 85.76 | 1.25 | $0.79^{ns}$ |
| | Out | 88.65 | 92.60 | 91.17 | 79.80 | 72.80 | 84.40 | 93.10 | 87.30 | 88.70 | 86.22 | 1.30 | |
| THI | In | 67.31 | 67.13 | 68.16 | 72.77 | 73.59 | 70.82 | 68.91 | 67.90 | 67.40 | 69.71 | 0.33 | $0.88^{ns}$ |
| | Out | 67.80 | 66.70 | 68.30 | 74.57 | 74.10 | 70.73 | 68.50 | 67.90 | 67.50 | 69.79 | 0.37 | |
| Air speed (m/s) | In | 3.00 | 2.91 | 3.07 | 3.13 | 2.45 | 2.85 | 2.42 | 2.86 | 3.21 | 2.83 | 0.07 | 0.00* |
| | Out | 0.58 | 0.68 | 0.87 | 1.88 | 2.37 | 1.65 | 1.53 | 1.34 | 2.13 | 1.55 | 0.16 | |

*Significant at P < 0.05; ns: non-significant at P > 0.05

**Table 2** Mean values of physiological responses of lactating dairy cows.

| Variable | Barn | Time (h) | | | | | Mean | SEM± | P value |
|---|---|---|---|---|---|---|---|---|---|
| | | 0300 | 0900 | 1200 | 1800 | 2100 | | | |
| Lay down percentage (%) | BC | 84.99 | 88.59 | 72.09 | 70.78 | 83.60 | 80.00 | 0.01 | 0.00* |
| | BT | 83.23 | 91.56 | 80.27 | 85.53 | 90.20 | 86.20 | 0.01 | |
| Respiration rate (times/min) | BC | 39.50 | 44.93 | 41.15 | 45.22 | 38.41 | 41.84 | 0.65 | 0.00* |
| | BT | 45.34 | 44.59 | 45.15 | 42.00 | 49.78 | 45.38 | 0.59 | |

*Significant at P < 0.05

**Table 3** Mean of milk yield and DMI sampling of lactating dairy cows.

| Variable | Barn | Day sampling | | | | | | Mean | SEM± | P value |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 3 | 5 | 8 | 10 | 12 | | | |
| Milk yield (kg/d) | BC | 18.99 | 22.03 | 25.50 | 24.77 | 23.12 | 22.55 | 21.87 | 0.96 | 0.00* |
| | BT | 38.67 | 39.26 | 38.82 | 37.71 | 39.19 | 39.15 | 38.85 | 0.26 | |
| DMI (kg/cow/d) | BC | 20.05 | 22.00 | 21.95 | 20.85 | 23.35 | 22.61 | 21.70 | 0.97 | 0.00* |
| | BT | 26.40 | 27.80 | 26.70 | 26.95 | 25.65 | 27.26 | 26.59 | 0.19 | |

*Significant at P < 0.05; ns: non-significant at P > 0.05

## Discussion

There were consistent results for both barns (Table 1). Surprisingly, environmental modifications did not lead to a decrease in ambient temperature or an increase in the relative humidity even though there were a number of fans in the barns. THI in the tunnel-ventilated barn did not decrease when compared to outside conditions. Suadsong et al (2008) reported high T and THI both outside and inside the barns in a tropical area (31.4°C, 83.1 outside and 26.5°C, 78 inside, respectively). Inside RH was relatively similar to the outside (74.6%); however, outside RH was lower (86.5%) than our findings (Table 1). The thermoneutral zone for dairy cows has a wide range: 13–18°C (McDowell 1972); 4–25°C (Yousef 1985); and 5–25°C (Jones and Stallings 1999).

The findings of the current study are consistent with those of Ruakura and Roads (2015) where ventilation provides the uniform distribution of air. In this study, the air speed in both barns was relatively similar during the study and ranged from 2.18 to 3.21 m/s. Shiao et al (2011) found that wind speed inside the tunnel-ventilated barn ranged from 1.23 to 2.06 m/s, which is lower than the results of our current study.

The THI in the tunnel-ventilated barn and outside of both barns exceeded the critical point of 72 at 1200 inside and outside both barns, suggesting that the cows were exposed to conditions conducive to heat stress for 3 h until 1500. Additionally, the cows were moved from inside the barn to the milking parlor at 1400, which continued the exposure to conditions that contribute to heat stress. However, sprinklers are provided by the commercial dairy industry for loading areas and for some locations on the path to the loading area. Sprinklers are used to alleviate the impact of heat stress on dairy cattle (Chan et al 1997). Shiao et al (2011) reported that using a sprinkler cooling system significantly increased the potential efficacy and feasibility of tunnel-ventilated barns for alleviating cow heat stress in hot and humid areas.

Cow milk yield in the BT barn was higher than that in the BC barn. High milk yield reflects the high availability of energy to produce milk (Gwayumba et al 2002). These results indicate that high milk may be due to higher DMI in the BT barn. It has been shown that increased DMI increases milk yield (Puggaard et al 2014). Smith et al (2006b) showed an 11% increase of DMI can increase milk yield to 2 kg of milk/cow day$^{-1}$. However, higher milk yield increased internal body heat (Wang et al 2018). Therefore, it is not surprising that cows in the BT barn had higher RR than those in BC barn; heat dissipation was expressed through higher RR. Additionally, heat accumulation was also influenced by the T inside the barn.

The T inside of the BT barn was slightly higher than that of the BC barn. Hahn et al (1997) showed that T was positively correlated with RR. Shiao et al (2011) reported RRs (42–53 times/min) similar to the present findings (Table 2). Increased RR in cows happens when the ambient T reaches 19°C and sweating commences at 25°C (Maia et al 2005ab). At 1200, the outside T reached 26.40°C (BC barn) and 25°C (BT barn), suggesting that dairy cows started to sweat when they were milked at 1400. Astuti and Sudarman (2015) suggested that increased RR was due to high humidity (greater than 78% relative humidity); RH in this study was reported greater than 78%. However, recommended RR for cow ranges between 26 and 35 times per min (Reece 1993).

Cow LDP in the BT barn was higher than the cows in the BC barn. Herbut and Angrecka (2018) reported that lying down behavior decreased when THI started to increase. However, since lying down behavior was only exhibited when the cows were inside the barn, our study cannot validate the findings of the previous research due to similar THI for both barns. Furthermore, this study is limited by the lack of information on lying times.

The tunnel-ventilated barn performed better and air speed was better distributed inside the barn in this tropical area. However, the barn showed similar air T, RH, and THI as the outside environmental conditions. Dairy cows had higher higher RRs with increased milk yield and DMI. The effects of a tunnel-ventilated cooling system on dairy cow lying down behavior in the tropics need more examination in future studies.

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