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EFFECTS OF TEMPERATURE AND HUMIDITY ON COW RESPIRATION RATES IN THREE KANSAS AND TWO NEBRASKA FREESTALL BARNS[1]

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Summary

Temperatures and humidities outside and inside freestall barns and cow respiration rates were monitored on three Kansas and two Nebraska commercial dairy farms during the summer of 1999. All farms had 4-row freestall buildings with different cooling systems. The first Kansas barn could be cooled naturally and mechanically using evaporative cooling pads located on the east and west walls. The second Kansas barn was ventilated naturally by manually lowering the sidewall curtains and without sprinkling or ventilation systems. The third Kansas barn was ventilated naturally and equipped with fans located over the freestalls and feed-line sprinklers. The first Nebraska barn was ventilated naturally and equipped with a sprinkler system over the feed line and fans over the freestalls. The second Nebraska barn was ventilated mechanically using evaporative cooling, fans installed over the freestalls, and a sprinkler system over the feed line. Evaporative cooling did not favorably modify the barn environment. It increased or decreased humidity and offset the effect of a lower barn temperatures, resulting in greater respiration rates of cows and overall less cow comfort than other systems that provided fans or sprinklers or both.

(Key Words: Environmental Stress, Heat Stress, Dairy Cattle.)

Introduction

Heat stress during the summer months reduces milk production. Cows begin to experience milk heat stress when the temperature humidity index (THI) exceeds 72. Dairy cattle produce large amounts of heat from both ruminal fermentation and metabolic processes. As milk production increases, the total amount of heat produced increases. In order to maintain body temperature with the normal range, cows must exchange this heat with the environment. This exchange primarily occurs via the lungs and skin. Under natural conditions and at temperatures below 70°F, more than 50% of the heat is lost via the skin. As the temperature reaches 80°F, only about 25% of the heat is lost through the skin and 75% is lost via the lungs. As the temperature increases above 80°F, a much greater percentage of the heat will be lost through the lungs and a smaller percentage through the skin.

Heat loss via the skin primarily occurs through exchange with the air. The amount of exchange under natural conditions is limited by air temperature, air movement, and relative humidity. Decreasing air temperature or increasing air movement will increase the loss via the skin. However, as temperature rises above 70°F, the temperature differential between the air and normal cow body temperature decreases. As the temperature approaches 103°F, the differential is minimal, and very little heat is lost via

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the skin, unless sprinklers are installed. Heat exchange is increased greatly by applying water to the skin. The water evaporates and absorbs the heat that increased the heat exchange between the skin and environment. Thus, at temperatures above 70°F, the use of sprinkler systems increases the amount of heat that is lost through the skin. Losses of heat through the skin are maximized when water is applied and then evaporated. A system that incorporates sprinklers that quickly wet the cow and then shut off while a fan moves large volumes of air around the cow will increase the number of wetting and evaporation cycles. In addition, the barn ventilation system must provide enough air exchange to move the humidity from water evaporation out of the building. Installation of circulation fans and construction of open sidewall barns increase air flow around the cow and building air exchange.

Heat loss through the lungs is accomplished by two methods. Heat is lost by increasing the temperature of the air inhaled and by evaporation of water in the lungs. Air exhaled by a cow will be approximately 100°F and contain greater than 95% relative humidity. The amount of cooling achieved through respiration is limited to the number of breaths per minute and the differences in temperature and relative humidity of the air inhaled and air exhaled. The temperature and humidity of the exhaled air are constant. At temperatures above 70°F, proper building design to maximize heat exchange via the skin and lungs is essential.

Dairy freestall barns generally are designed to maximize natural ventilation. Supplemental cooling systems (fans and sprinkler) are added to help reduce heat stress. The basic concept has been to create air movement via natural and mechanical methods. The addition of sprinkler systems at the feed line allows the cows to take advantage of water evaporation off the body to increase skin heat exchange. Recently, two barns (one in Kansas and one in Nebraska) included an evaporative cooling system in the building design.

Evaporative cooling utilizes water evaporation to reduce the temperature of air. Water absorbs heat as it evaporates and reduces air temperature. However, evaporative cooling also increases the relative humidity of the air. The degree of cooling is influenced by the temperature and relative humidity of the air introduced into the cooling pad, where evaporation occurs. High temperature and low relative humidity will allow for a larger reduction in temperature than high temperature and high relative humidity. Thus, relative humidity may limit the effectiveness of this system. Another possible limitation of an evaporative cooling system for dairy freestall barns is the water vapor produced from dairy cattle respiration. Cows produce large volumes of water vapor and urine, which will increase the relative humidity of the air in the barn. This humidity must be removed by building air exchange. If the humidity is not removed, the heat exchange capacity of the lungs due to evaporation is reduced. To be effective, the evaporative cooling system must increase the heat exchange capacity of the lungs via a lower temperature in the presence of greater relative humidity. This means that either the evaporative cooling system is more energy efficient in the evaporation process than the lung of the cow or that the reduced air temperature would increase the heat loss of the skin more than the increased relative humidity reduced the heat exchange in the lungs. The efficiency of water evaporation is likely similar between the evaporative cooling pad and the cow, because the same laws of physics apply to both. Hence, the potential advantage of evaporative cooling systems would be increased loss of heat through the skin.

The purpose of this study was to monitor temperatures and relative humidities outside and inside five freestall barns with different cooling systems. Respiration rates of cows also were monitored to evaluate their responses to different environmental conditions in the barns.

Procedures

Five freestall barns, three in western Kansas and two in western Nebraska, were monitored during the summer of 1999. Temperatures and relative humidities outside and inside barns were monitored continuously for 672 hr (Kansas, July 21 -August 17, 1999) and 864 hr (Nebraska, July 30 - September 3, 1999). Respiration rates were obtained in the morning (7-8:00 a.m.), afternoon (2-3:00 p.m.), and night (9-10:00 p.m.) from 50 cows per farm on 3 (Kansas dairies) or 2 (Nebraska dairies) different days. All barns were four-row freestall barns but differed in construction and cooling system design.

Barn one (A-KS) was a 106-ft wide, 4-row, freestall barn oriented north-south and located in southwest Kansas. The building was ventilated naturally and mechanically. It had a galvanized uninsulated roof on a 4/12 pitch. Sidewalls were 12.5 ft high. Located in the upper 30 inches of the sidewalls were evaporative pads that ran the length of the building. The lower portion of the sidewall was curtained. Roof fans were located on 12-ft centers along the ridge of the building, and there was no peak opening. The 36-inch fans (11,000 cfm/fan) moved air through the evaporative pads and exhausted through the ridge. A portion of the fans operated when curtains were opened to exhaust heat from the peak of the building. The barn had no sprinkler system along the feed line.

Barn two (B-KS) was a 100-ft wide, 4-row, freestall barn oriented east to west and located in southwest Kansas. The building had a galvanized uninsulated roof on a 3/12 pitch. The ridge opening was 18 inches. Curtain sidewalls were 10 ft high. The building was ventilated naturally and had no sprinkler or mechanical ventilation systems.

Barn three (C-KS) was 100-ft wide, 4-row, freestall barn oriented east to west and located in southwest Kansas. The building had a galvanized uninsulated roof on a 3/12 pitch. The ridge opening was 18 inches. Sidewalls were 11 ft high with a curtain used on the south side. The north side had a 30-inch opening below the eave with the remainder of the wall being solid. The building was ventilated naturally and had sprinkler and mechanical ventilation systems. The sprinkler systems had a spray nozzle located every 88 inches along the feed line. The ventilation system had 48-inch fans (20,000 cfm/fan) over the freestalls on 28-ft centers. The bottom of the sprinkler line and fans were located 7 ft above the floor. The sprinkler and ventilation systems were controlled thermostatically to operate when temperatures exceeded 72°F.

Barn four (D-NE) was a 96-ft wide, 4-row, freestall barn oriented east to west and located in north central Nebraska. The building had a galvanized uninsulated roof on a 3/12 pitch. The ridge opening was 18 inches. Sidewalls were 14 ft high with a 13-ft curtain. The building was ventilated naturally and had sprinkler and mechanical ventilation systems. The sprinkler systems had a spray nozzle located every 21 ft along the feed line. The ventilation system had 36-inch fans (11,000 cfm/fan) over the freestalls on 48-ft centers. The bottom of the sprinkler line and fans were located 8 ft above the floor. The sprinkler and ventilation systems were controlled manually.

Barn five (E-NE) was a 96-ft wide, 4-row, freestall barn oriented east to west and located in north central Nebraska. The building was ventilated mechanically. It had a galvanized insulated roof on a 3/12 pitch. Sidewalls were 12 ft high and solid except for sidewall inlets located on the south and north sides running the length of the building. A high pressure line was located just above the sidewall inlets and sprayed a fine mist of water into the incoming air stream. The inlet was approximately 8 inches wide and located about 9 ft above the floor. Roof fans were located on 12-ft centers in the ridge of the building. The 36-inch fans (11,000 cfm/fan) moved air from the sidewall inlets located on the south and north sides with the exhaust occurring at the ridge. Sprinkler systems were located over the sidewall inlets and feed line. The feed line system used 0.5 gal/min nozzles located every 12 ft. The sidewall inlet system used

1.5 gal/min nozzles located on 6-ft centers. Circulation fans were installed over the freestalls.

Results and Discussion

Kansas Barns

Inside barn temperatures (Table 1) at the Kansas farms differed (*P*<.05) with C-KS being highest (80°F) and A-KS the lowest (76°F). Barn relative humidity was greater (*P*<.05) for A-KS than for B-KS and C-KS (72.1 vs 59.6 and 59.0%). Outside relative humidity was similar for all farms. Outside temperature was greatest (*P*<0.05) for C-KS and lowest for A-KS. The cooling cells of the A-KS barn reduced ambient temperature 2°F and increased humidity 12.2 units, resulting in an increased THI inside the barn. These differences were significant (*P*<.05) as compared to the other systems.

Mean respiration rates (Table 2) were greater (*P*<.05) for cows in A-KS than for cows in B-KS and C-KS (83.5 vs 60.4 and 63.0 breaths/minute). Rates were higher (*P*<.05) for A-KS cows than for cows in the two other barns during morning, afternoon, and night. Temperature humidity index values before and during measurements of respiration rates were similar in the morning and afternoon periods but differed at night. The evaporative cooling system lowered barn temperature but increased barn humidity, resulting in greater THI values during the entire study period. Greater THI values accounted for greater respiration rates of cows, even though THI values were not greater for the A-KS barn. These results indicate that THI, which does not account for the effects of sprinkler systems or air movement, was not a suitable tool for predicting cow comfort or respiration rates influenced by conditions more than 2 hr prior to their measurement.

Nebraska Barns

Barn temperature, relative humidity, and THI (Table 3) were greater (*P*<.05) for E-NE than D-NE. The effect of the evaporative cooling system increased THI more (*P*<.05) than outside temperature changes of the other barn. Outside conditions were similar for both locations. Mean respiration rates and average THI values when respiration rates were assessed were not different between barns. However, respiration rates of cows in the morning were greater (*P*<.05) for E-NE than for D-NE. Respiration rates of cows in these two barns followed the same trends observed for the barns in Kansas.

Conclusions

These results showed that evaporative cooling increased barn humidity and either lowered or increased barn temperature. In the case of the dairy that showed a reduced barn temperature, sidewall curtains were lowered at night, and the evaporative pad was bypassed during evening hours. Thus, the barn was cooled to near ambient temperature at night. In the case of the other evaporatively cooled barn, curtains were not lowered at night, and the building temperature remained above the outside temperature. Evaporative cooling of freestall barns increased cow respiration rates and did not improve the environmental conditions for cows. Considering the methods by which a cow reduces body temperature, evaporative cooling did not sufficiently reduce air temperature to offset the reduction in evaporative lung cooling due to increased humidity. Additional studies are needed to evaluate system performance based on other management strategies.

Table 1. Comparison of Temperature, Relative Humidity, and THI Outside and Inside Three Freestall Barns in Kansas[1]

	Barns			
Item	A[2]-KS	B[3] - KS	C[4] - KS	SE
Inside barn temperature, °F	76[a]	78[b]	80[c]	.2
Inside barn relative humidity, %	72[b]	60[a]	59[a]	.8
Inside barn THI[1]	73[b]	72[a]	74[c]	.1
Outside temperature, °F	78[a]	78[a]	80[b]	.2
Outside relative humidity, %	60	58	60	.7
Outside THI[1]	72[a]	72[a]	73[b]	.1
Temperature difference[5], °F	-2[a]	0[b]	0[c]	.2
Relative humidity difference[5], %	12[b]	1[a]	-1[a]	.8
THI[1] difference[5]	1[c]	0[a]	1[b]	.1

[1]THI = Temperature humidity index. Data were collected from July 30 through September 3, 1999. THI = temperature,°F - (.55 - .55 × percent relative humidity/100) × (temperature, °F - 58).
[2]A-KS = 4-row Kansas freestall barn with evaporative cooling.
[3]B-KS = 4-row Kansas freestall barn without any cooling system.
[4]C-KS = 4-row Kansas freestall barn with freestall fans and a feed-line sprinkler system.
[5]Inside barn minus outside.
[a,b,c]Means within the same row with unlike superscripts differ (*P*<.05).

Table 2. Respiration Rate of Dairy Cows and Freestall Barn THI at Three Dairy Farms in Kansas at Different Periods of the Day[1]

	Barns			
Item	A[2]-KS	B[3]- KS	C[4]- KS	SE
Morning respiration rate, breaths/min	74[a]	58[b]	63[b]	3
Afternoon respiration rate, breaths/min	93[b]	80[a]	83[a]	3
Night respiration rate, breaths/min	84[b]	60[a]	63[a]	3
Average respiration rate, breaths/min	84[b]	66[a]	70[a]	2
Morning THI[1]	69	68	69	1
Afternoon THI[1]	78	79	80	1
Night THI[1]	76	77	79	1
Average THI[1]	74	75	76	1

[1]THI = Temperature humidity index measured during and 2 hrs prior to assessing respiration rates of cows. THI = temperature,°F - (.55 - .55 × percent relative humidity/100) × (temperature, °F - 58).
[2]A-KS = 4-row Kansas freestall barn with evaporative cooling.
[3]B-KS = 4-row Kansas freestall barn without any cooling system.
[4]C-KS = 4-row Kansas freestall barn with freestall fans and a feed-line sprinkler system.
[a,b,c]Means within the same row with unlike superscripts differ (*P*<.05).

Table 3. Comparison of Temperature, Relative Humidity, and THI[1] Outside and Inside Two Freestall Barns in Nebraska[1]

	Barns		
Item	D[2]-NE	E[3]-NE	SE
Inside barn temperature, °F	76[a]	77[b]	.2
Inside barn relative humidity, %	71[a]	81[b]	1.0
Inside barn THI[1]	72[a]	74[b]	.2
Outside temperature, °F	76	77	.2
Outside relative humidity, %	74	73	.6
Outside THI[1]	73	73	.2
Temperature difference[4], °F	0	0	.3
Relative humidity difference[4], %	-3[a]	8[b]	1.4
THI[1] difference[4]	-1[a]	1[b]	.2

[1]THI = Temperature humidity index. Data were collected from July 21 through August 17, 1999. THI = temperature, °F - (.55 - .55 × percent relative humidity/100) × (temperature, °F - 58).
[2]D-NE = 4-Row Nebraska freestall barn with freestall fans and a feed-line sprinkler system.
[3]E-NE = 4-Row Nebraska freestall barn with evaporative cooling, feed-line circulation fans and a feed-line sprinkler system.
[4]Inside barn minus outside.
[a,b]Means within the same row with unlike superscripts differ ($P<0.05$).

Table 4. Respiration Rate of Dairy Cows and Freestall Barn THI at Two Dairy Farms in Nebraska at Different Periods of the Day[1]

	Barns		
Item	D[2]-NE	E[3]-NE	SE
Morning respiration rate, breaths/min	59[a]	71[b]	7
Afternoon respiration rate, breaths/min	84	88	7
Night respiration rate, breaths/min	76	70	7
Average respiration rate, breaths/min	73	76	7
Morning THI[1]	68	70	3
Afternoon THI[1]	79	80	3
Night THI[1]	72	79	3
Average THI[1]	73	76	3

[1]THI = Temperature humidity index measured during and 2 hr prior to assessing respiration rates of cows. THI = temperature, °F - (.55 - .55 × percent relative humidity/100) × (temperature, °F - 58).
[2]D-NE = 4-Row Nebraska freestall barn with freestall fans and a feed-line sprinkler system.
[3]E-NE = 4-Row Nebraska freestall barn with evaporative cooling, feed-line circulation fans and a feed-line sprinkler system.
[a,b]Means within the same row with unlike superscripts differ ($P<0.05$).