Effectiveness of Cow Cooling Strategies Under Different Environmental Conditions

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Introduction

Thermal stress in cattle results in major decreases in dairy production each summer. These decreases have been documented in many studies and reviews (Armstrong, 1994, Collier, et.al., 1982, Ravagnolo, et.al., 2000 and Ray, et.al. 1992). Igono and others (1992) proposed that the Temperature Humidity Index (THI) could be used to evaluate the thermal stress of the environment. This index combines relative humidity and temperature into a single value to estimate the potential environmental heat load. An environment is generally considered stressful for cattle when the THI exceeds 72. When THI is above this level, adverse affects are expected in cattle. Others have suggested (Hahn, et al., 1992) that feed intake of cattle will be reduced when temperatures exceed 75 °F. Production losses can be minimized by proper heat abatement measures. However, the measures must also be cost effective and provide an economic return to the dairy operation.

Heat Exchange Mechanisms

Dairy cattle produce large amounts of heat from both ruminal fermentation and metabolic processes. As production increases, the total amount of heat produced increases. A high producing lactating cow will produce about 4,500 British Thermal Unit (BTU)/hr. In order to maintain body temperature within the normal range, cows must exchange this heat with the environment. Cattle exchange heat through the mechanisms of convection, conduction, evaporation and radiation. It is important to remember that heat exchange is a two-way street; the cow gives and receives heat energy from the environment depending upon the condition. For example, if the air temperature is lower than the body temperature of a cow standing in the sun, heat is transferred by conduction, convection and radiation to the environment while the environment is transferring heat to the cow by radiation from the sun. Protection from solar radiation by providing adequate shade is the first step in reducing heat stress in dairy cattle. University research station scientists recognized summertime stress as a major dairy production problem in the 1940's. Extensive work at the Missouri experiment station sought to describe and define the heat loss mechanisms of dairy animals (Kibler and Brody, 1949, 1950, 1952 and 1954). One of the most significant findings was an accurate accounting of heat loss for dairy cattle by various mechanisms over a wide range of environmental temperature (Figure 1). At temperatures above 70° F, the heat loss is primarily due to moisture evaporation from the skin and lungs. As temperatures exceed 90° F, over 85% of the total heat dissipation is due to vaporization of water from the body surface and lungs. It is important to note that cattle in these studies were not cooled. Researchers were simply trying to establish the mechanisms of heat loss and the relative importance of each. Brody and others (1954) would later suggest that at a temperature of 95° F, wetting the hair and skin would greatly increase heat dissipation due to the large surface area of the hair allowing for greater vaporization of the water.

Cooling Inspired-Air

Zone cooling or "snout" cooling has been utilized in the swine industry and a few studies have evaluated this method for dairy cattle. Kleiber and Regan (1935) reported cooling inspired-air 40 to 50 ˚F below ambient conditions (90 to 99 ˚F) reduced respiration rates. A later report (Hahn, et al., 1965) showed that cows in an 85 ˚F environment benefited from inspired-air cooled to 50 to 60 ˚F. Researchers observed increased feed intake and milk production coupled with decreased rectal temperature and respiration rates when cows were given access to cooled air for breathing. Further research (Roussel and Beatty, 1970) showed that cooling inspired-air 15 ˚F below daytime (95 to 91 ˚F max temperature) and 5.5 ˚F below nighttime ambient (74 to 71 ˚F minimum temperature) temperature increased milk production 19 percent as compared to control cows. Air conditioning was utilized in this study and no report was available on the relative humidity of the control and cooled cows. If differences in relative humidity existed between the treatments, some of the response could have been due to relative humidity and not temperature alone. Other researchers (Canton, et al., 1982) reported that when cattle were exposed to black globe temperatures of 86 ˚F (shade) and 104 ˚F (no shade) with inspired-air cooled to 46 to 70 ˚F, inspired air needed to be cooled below 70 ˚F to reduce respiration rates and below 60 ˚F to reduce both respiration rate and rectal temperature of cattle without shade. The authors concluded that a well-designed shade structure was more beneficial and economical in reducing heat stress than inspired-air cooling without shade. It is interesting to note that in most of these studies inspired-air needed to be cooled to below 70˚F to reduce heat stress in dairy cattle. Brody had concluded that environmental temperature must be maintained 25 ˚F below body temperature to prevent heat stress.

Soaking and Airflow

Researchers in Louisiana conducted several experiments in the late 1940's to determine the effects of utilizing sprinkling, shade and supplemental air movement to cool dairy cows (Seath and Miller 1947 and 1948). They reported that sprinkling cows prior to entering a shade reduced respiration rates by 65-81% and body temperatures by 46-59% over shade alone. They also found that using sprinkling in combination with supplemental airflow resulted in a rapid change in body temperature and respiration rate and was superior to either a fan or sprinkling alone.

Wetting frequency and level of supplemental airflow have been shown to have a dramatic impact upon the heat exchange rate of dairy cattle. Hillman and coworkers (2001) showed that increasing airflow and wetting frequency had a dramatic effect on the evaporative heat loss from the skin of dairy cows (Figure 2). Heat loss increased 2 to 8 fold when wetting frequency was increased from 0.4 to 4.9 mph.

In a study conducted at Kansas State University, several different cooling treatments were evaluated (Table 1). Body and surface temperature of the rear udder and thurl were monitored every 5 minutes during the study. Body temperature (Figure 3) dropped the fastest with soaking the cow every five minutes in addition to providing supplement airflow. Just the fan alone did not significantly reduce body temperature. Increasing sprinkling frequency reduced body temperature, but not to the same degree when used in conjunction with supplemental airflow. The surface temperatures of the rear udder and thurl showed a similar pattern as body temperature.

Evaporative Cooling

When choosing heat abatement measures, it is important to remember these concepts. There are two general approaches to cooling dairy cattle. One must either modify the environment to prevent heat stress or utilize methods that increase heat dissipation from the skin of cattle. Air conditioning is the ultimate method to modify a warm environment. It reduces air temperature and relative humidity greatly lowering the THI of the environment. On a commercial basis, this is not an economical choice for modifying the environment of dairy cattle. A more economical method to reduce air temperature is by evaporative cooling. When water evaporates it absorbs heat, reducing the temperature, but when water evaporates it also increases the relative humidity due to the increased level of water vapor present.

The combination of tunnel ventilation with evaporative cooling systems has been used in swine and poultry operations for many years to cool the environment. Recently, these systems have been installed in some Midwest dairy facilities. It has been reported (Huhnke, et. al. 2001) that evaporative cooling could reduce the number of hours at higher level of temperature-humidity index (THI) in some environments. Evaporative cooling has been used very successfully to cool dairy cattle in hot arid climates. Under arid conditions and high environmental temperatures, there is a great potential to reduce temperature and THI (Figures 2 and 3). However, as relative humidity increases and or temperature decreases, the potential of evaporative cooling to modify the environment decreases. Data presented in Figures 2 and 3 are based on a 100% efficiency of evaporation to 90% relative humidity. The efficiency of evaporative cooling equipment ranges between 50 and 80% reducing the effect of the systems. In the Midwest, high relative humidity reduces the potential of evaporative cooling. As relative humidity increases above 70%, the potential reduction in THI is less than 10%.

Very few studies have been reported in the literature concerning the effects of evaporative cooling on the stress level of dairy cattle housed in humid environments. Brown and others (1974) evaluated the effects of evaporative cooling in tie stall housing at Mississippi State University during the summers of 1970, 1971 and 1972. Milk production was significantly increased in one of the three summers and respiration rates were significantly lowered in two of three summers by evaporative cooling as compared to the controls. The study showed that evaporative cooling could reduce peak daytime temperatures however the authors questioned the long term benefits of the system.

As dairy producers have adopted evaporative cooling systems, the K-State Dairy Team has had the opportunity to monitor several systems beginning in the summer of 1999. The two barns evaluated in 1999 were both modified systems utilizing roof peak ventilation fans (Brouk, et al. 2001). Air was drawn through the sidewall with either cellulose evaporation pads or a narrow slit equipped with a high-pressure mist system. Temperature and relative humidity were monitored and recorded every fifteen minutes at various points in the building from late July until early September. In addition, naturally ventilated freestall barns located in the area were also monitored. Respiration rates of cattle under heat stress were evaluated and recorded in each of the barns. As compared to the ambient conditions, evaporative cooled barns were cooler in the afternoon hours but warmer during the late evening and early morning hours. When the data were averaged by day average temperature was less than 2 ºF different than ambient conditions. Average THI were actually higher than ambient conditions. Cattle housed in the evaporative cooled barns had greater morning respiration rates as compared to cattle housed in a naturally ventilated freestall barn, indicating a greater level of environmental stress associated with greater THI in those barns. The system designs did not effectively alter the environmental conditions enough to reduce heat stress. It should be noted that both of these systems utilized roof exit fans and were not tunnel ventilated but rather roof ventilated.

During the summer of 2000, two barns with tunnel ventilation and evaporative pads were evaluated. The level of THI was reduced during the afternoon hours as compared to ambient conditions. However, the degree of reduction was greater for one barn than the other. Data indicated that the evaporative cooled tie stall barn was cooler than either the two-row or four-row naturally ventilated freestall barn. This was due to differences in ambient conditions and barn design. This tie stall had an excellent design and provided an airflow of 500-600 ft/sec and a small cross-sectional area. The other barn was much larger and reductions during the afternoon hours were less than the smaller barn and offset by increases during the evening and night hour. It was also noted that air temperature increased and relative humidity decreased at greater distances from the air intake at the evaporative pads. The effects of barn and system design are important factors in determining the efficiency of evaporative cooling on Midwest dairy facilities.

Data from the 1999 and 2000 studies were summarized by hours above and below a THI of 75 (Table 2). The researchers observed a reduction in total hours above a THI of 75 with ranges from –10.3 to +3.5%. Factors critical to the correct design of the system include airflow, air turnover, cross-sectional area, and evaporation potential. When using evaporative cooling systems, one is trying to reduce the environmental stress level. Evaporative cooling is only effective if the THI is actually lowered as compared to ambient conditions. It is important to recognize that as air temperature is lowered due to water evaporation the potential to evaporate moisture from the skin of cattle is also reduced. The net effect of evaporative cooling of air must be greater than the loss of cooling from moisture evaporation from the skin of cattle or cattle stress will increase rather than decrease under heat stress conditions. As a result of questionable system design, some evaporative cooled barns may be more stressful than conventional freestall barns that are naturally ventilated as was observed in the 1999 studies.

During the summer of 2001 six tunnel ventilated tie stall barns in northeastern Missouri and southeastern Iowa were evaluated. Three of the barns were equipped with cellulose evaporative pads and three were not. Temperature and relative humidity were recorded continuously for 11 weeks from July 1 to September 15, 2001. On three consecutive days under stress conditions, respiration rates, rectal temperature, and skin temperature of three sites were evaluated on 20 cows in each barn (Table 3). Cattle housed in tie stall barns equipped with evaporative cooling had lower average respiration rates (65.7 vs 70.3 breaths/min) than those housed in barns without evaporative cooling. However, rates observed in the morning and at night were not different, only the afternoon rates differed significantly. Average rectal temperatures were also lower for the cows housed in evaporative cooled barns. Similar to respiration rates, the greatest differences existed during the afternoon. Skin temperatures followed respiration rates and rectal temperatures and were significantly lower for the cattle housed in the barns equipped with evaporative cooling with the greatest differences observed during the afternoon.

Greatest changes from ambient conditions are noted during the 1:00 pm to 8:00 pm period. During this period temperature decreases up to 8.25 ºF, relative humidity increases up to 30% and THI decreases up to 3.25 units as compared to the ambient conditions. There is considerable variation in the response over the 11 wk trial. During the period from 9:00 pm to 4:00 am and the period from 5:00 am to 12:00 pm, the evaporative pads were not utilized due to the ambient humidity level reaching about 85%. Thus the systems had little effect upon the barn environment during these periods.

As compared to the barns with only tunnel ventilation, barns with evaporative cooling had a greater percentage of July and August hours at a THI level below 70 and eliminated the hours in the 85-90 THI category (Figure 6) during the hours of 1:00 pm and 8:00 pm. Evaporative cooling reduced the heat stress during the afternoon hours without increasing the stress during the evening and night hours as compared to the tunnel ventilated barns. This study showed significant advantages for the evaporative cooled and tunnel ventilated barns in terms of respiration rates, rectal temperatures and barn environment.

Conclusions

Can evaporative cooling be utilized in combination with tunnel ventilation to reduce heat stress of dairy cattle housed in the Midwest? It depends upon several factors. First, what is the temperature and evaporation potential of the environment? In many locations, the afternoon relative humidity may be too great to take advantaged of evaporative cooling. In the 2001 study area, nighttime relative humidity was near the saturation point, limiting the systems. However, afternoon relative humidity dropped to a level that allowed for evaporation potential making the systems effective in reducing the severity of the stress. In hot arid conditions, the system would work well. However, in high humidity locations its effectiveness would be limited by evaporation potential.

If the environment will allow for evaporation potential, one should then consider barn design. The barns studied in 2001 were well designed and had a small cross-sectional area. This allowed for high levels of air exchanged with minimal fan horse power. These barns were also less than 300 ft in length and approximately 40 ft wide with ceiling heights of less than 9 ft. All barns also had a correct pad area. These systems were utilized during the afternoon hours and were shut down during the high humidity evening and night hours. The net effect was a reduction in animal stress as compared to tunnel ventilation only. When sound design criteria are not followed, problems arise as was noted in the 1999 study. Based on the 2000 data, there may be some advantages of the evaporative system in smaller barns as compared to large freestall barns. Smaller barns (tie stall) have a much smaller cross-sectional area than a large freestall barn. If one builds a barn with 12 ft side-walls and a 4/12 roof pitch, over 25% of the cross-sectional area is the rafter area. One approach is to utilize a ceiling or false ceiling along underside of the rafters to reduce the cross-sectional area that is tunnel ventilated and evaporative cooled. It would also be possible to lower the sidewall height and roof pitch. Choosing to do this results in a structure that must always be mechanically ventilated. This approach has been taken in the swine industry. Trying to mix natural and mechanical ventilation systems has had limited success in the swine industry and the same is likely in the dairy industry. To work effectively, evaporative cooling and tunnel ventilation systems must be correctly designed. Suggested guidelines to tunnel ventilation have been made by Tyson and others (1998).

The third thing to consider is the effectiveness of evaporative cooling with other heat abatement methods. Work at KSU has shown the effectiveness of soaking cattle and then evaporating the water from skin. This has been shown to be highly effective in reducing respiration rates and skin temperatures. However, to date no study has evaluated in a head-to-head comparison the effect of evaporative cooling verses soaking and evaporation from the skin surface. It would be more efficient to dissipate heat from the skin via evaporation rather than exchange via convection. However additional research is needed to determine the effects of tunnel and evaporative cooling systems on milk production as compared to conventional methods of cow cooling.

Recommendations for dairy cow cooling strategies.

1. Consider the temperature of the location. If ambient temperatures are greater than 100 ˚F for a significant amount of the day and for a period of several weeks, consider evaporative cooling to reduce environmental temperature.

2. Consider the relative humidity of location. High relative humidity limits evaporative cooling. Consider the afternoon potential to reduce afternoon stress. In some cases, afternoon relative humidity is lowered enough to allow evaporative cooling to be effective.

3. Consider cooling mechanism of the cow. Evaporation of water from the surface of the cow's body effectively cools the cow

4. Increase soaking frequency at feedlane as temperature increases. Soaking will require .35 gallon of water per headlock per soaking cycle.

    a. 75 - 82° F once every 15 minutes

    b. 83 - 87° F once every 10 minutes

    c. >87° F once every 5 minutes

5. Provide minimal supplemental airspeed of 6-7 mph over feedlane and 3-3.5 mph over freestalls.

6. If utilizing evaporative cooling systems, consider adding feedline soakers to increase cow cooling during peak feeding periods.

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Table 1. Experimental treatments of KSU study.

Treatment	Soaking frequency*	Supplemental Airflow
0	None	None
0 + F	None	700 cfm
5	Every 5 minutes	None
5 + F	Every 5 minutes	700 cfm
10	Every 10 minutes	None
10 + F	Every 10 minutes	700 cfm
15	Every 15 minutes	None
15 + F	Every 15 minutes	700 cfm

*.35 gallon/headlock applied in 1 minute

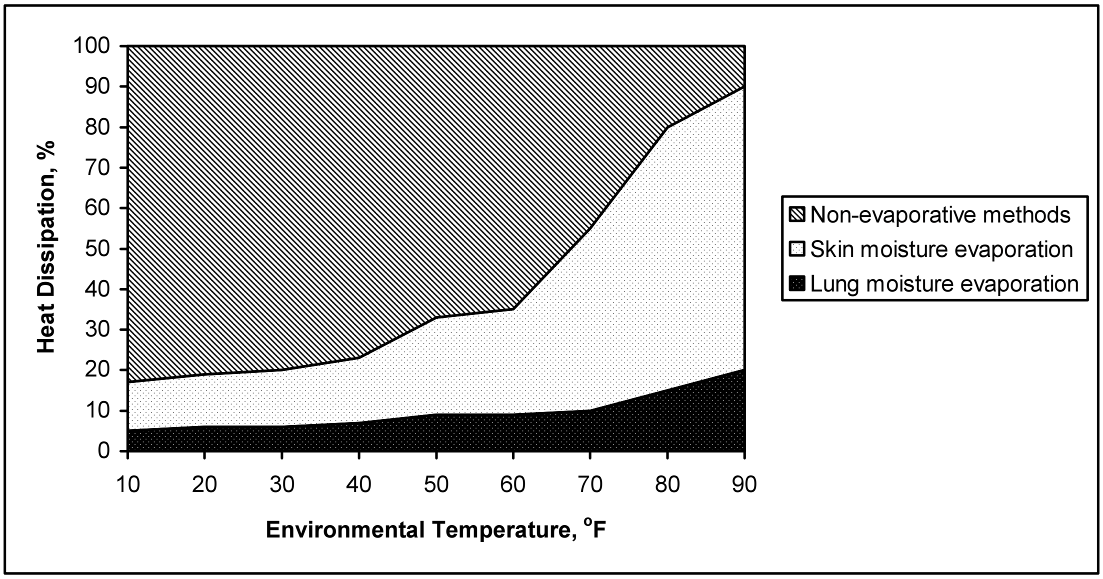
Table 2. Effect of evaporative cooling on the percent of summer hours below and above Temperature-humidity index (THI) of 75 in four Midwest dairy facilities.

<table>
<tr><th rowspan="2">Barn</th><th rowspan="2">Summer</th><th rowspan="2">System</th><th rowspan="2">Location</th><th colspan="2">Percentage of Hours</th></tr>
<tr><th>THI<75</th><th>THI=>75</th></tr>
<tr><td rowspan="3">A</td><td rowspan="3">2000</td><td rowspan="3">Pads/Tunnel</td><td>Barn</td><td>67.5</td><td>34.3</td></tr>
<tr><td>Ambient</td><td>55.4</td><td>44.6</td></tr>
<tr><td>Change</td><td colspan="2">-10.3</td></tr>
<tr><td rowspan="3">B</td><td rowspan="3">1999</td><td rowspan="3">Pads/Roof Exit</td><td>Barn</td><td>79.2</td><td>20.8</td></tr>
<tr><td>Ambient</td><td>75.7</td><td>24.3</td></tr>
<tr><td>Change</td><td colspan="2">-3.5</td></tr>
<tr><td rowspan="3">C</td><td rowspan="3">1999</td><td rowspan="3">High Pressure/Roof</td><td>Barn</td><td>73.3</td><td>26.7</td></tr>
<tr><td>Ambient</td><td>76.9</td><td>23.1</td></tr>
<tr><td>Change</td><td colspan="2">3.6</td></tr>
<tr><td rowspan="3">D</td><td rowspan="3">2000</td><td rowspan="3">Pads/Tunnel</td><td>Barn</td><td>76.5</td><td>23.5</td></tr>
<tr><td>Ambient</td><td>70.5</td><td>29.5</td></tr>
<tr><td>Change</td><td colspan="2">-6.0</td></tr>
<tr><td colspan="4">Average Change</td><td colspan="2">-4.05</td></tr>
</table>

Table 3. Effect of tunnel ventilation with and without evaporative cooling on the average respiration rate, rectal temperature and skin temperatures of lactating Holstein cows at three different time periods of the day.

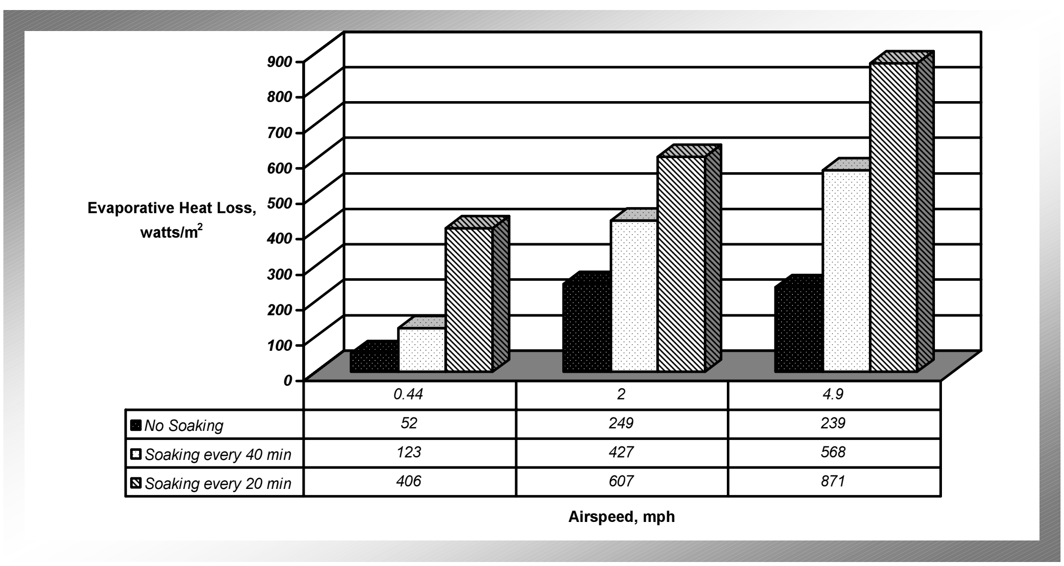
Measurement	Barn	Period of Day			Average of Day	Cooling System Effect
		Morning	Afternoon	Night		
Respiration rate, breaths/min	Tunnel + Evap	55.0	73.5[a]	68.7	65.7[a]	
	Tunnel	56.5	83.8[b]	70.6	70.3[b]	P<.01
Rectal Temperature, °F	Tunnel + Evap	101.4	102.3[a]	102.5	102.1[a]	
	Tunnel	101.6	103.0[b]	102.7	102.4[b]	P<.01
Thurl Skin Temperature, °F	Tunnel + Evap	90.0	93.2[a]	93.4[a]	92.2[a]	
	Tunnel	91.8	97.5[b]	94.6[b]	94.6[b]	P<.01
Rear Udder Skin Temperature, °F	Tunnel + Evap	92.4	95.4[a]	95.0	94.3[a]	
	Tunnel	92.5	98.3[b]	95.4	95.4[b]	P<.01
Ear Skin Temperature, °F	Tunnel + Evap	90.3	93.3[a]	93.2	92.2[a]	
	Tunnel	90.4	96.3[b]	93.2	93.3[b]	P<.01

[ab]Measurement means within the same column with different superscripts differ.



Adapted from Kibler and Brody, 1950.

Figure 1. Partition of total heat loss of dairy cattle without supplemental cooling.



Adapted from Hillman, et.al. 2001

Figure 2. Effect of soaking and airflow on evaporative heat loss from the skin of cattle.

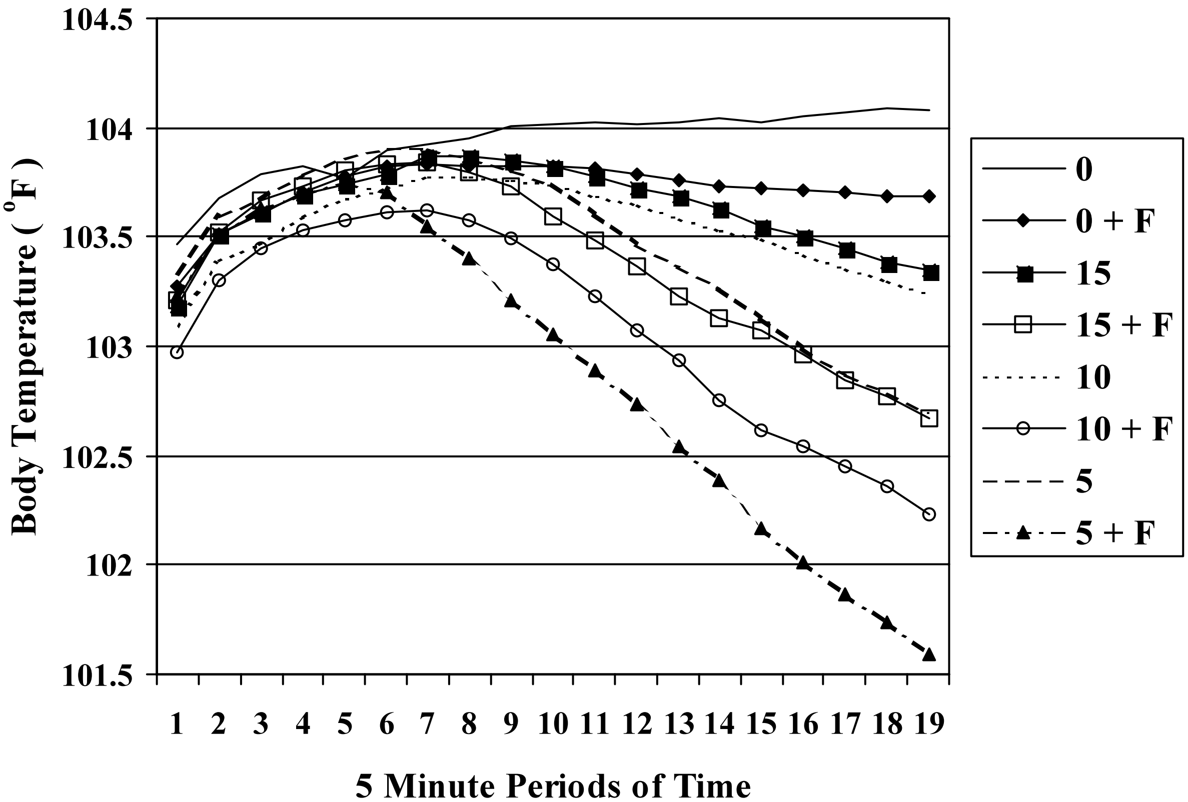


Figure 3. Effect of Cooling Systems Upon Body Temperature Over 95 Minutes of Cooling.

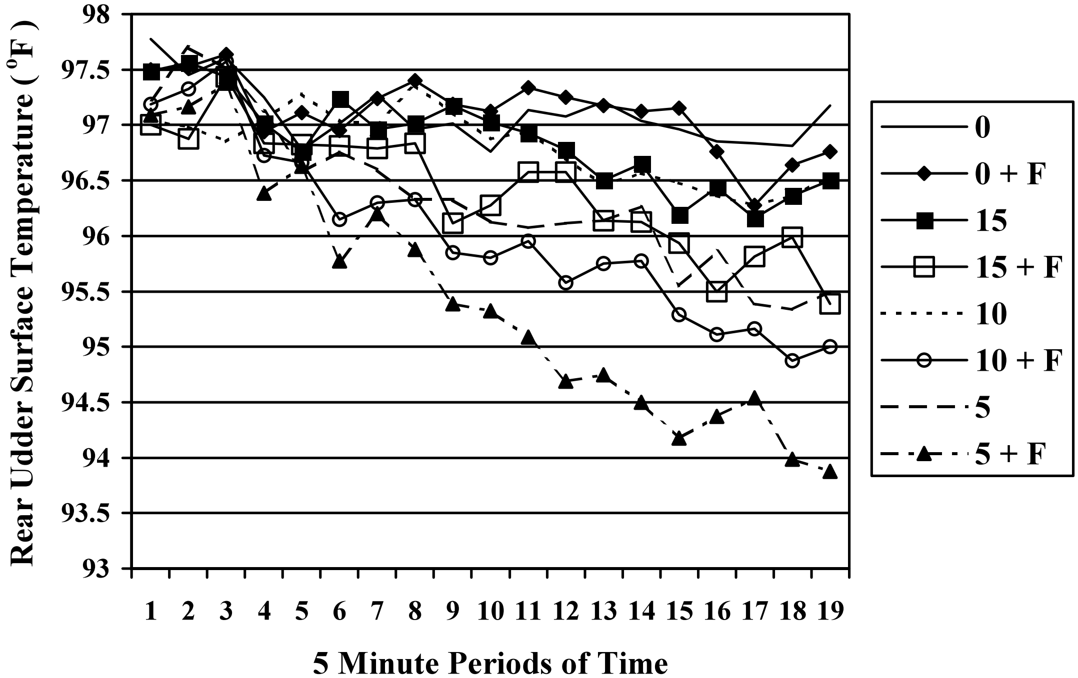


Figure 4. Effect of cooling systems upon rear udder surface temperature over 95 minutes of cooling.

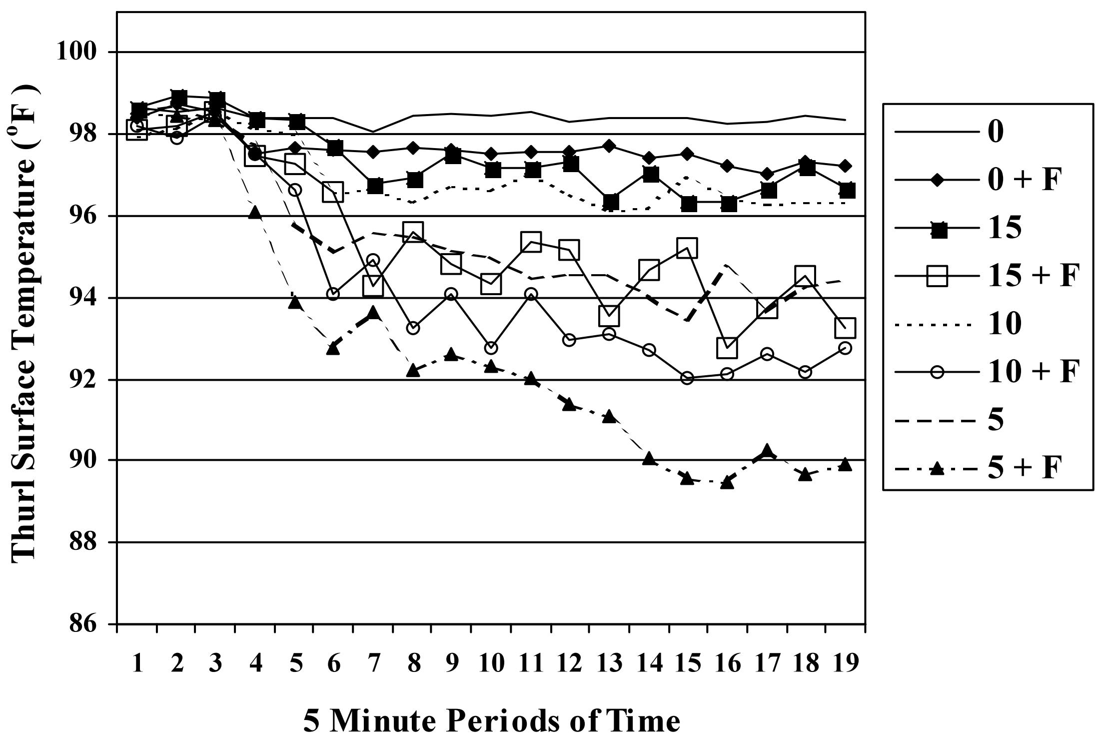


Figure 5. Effect of cooling systems on thurl surface temperature over 95 minutes of cooling.

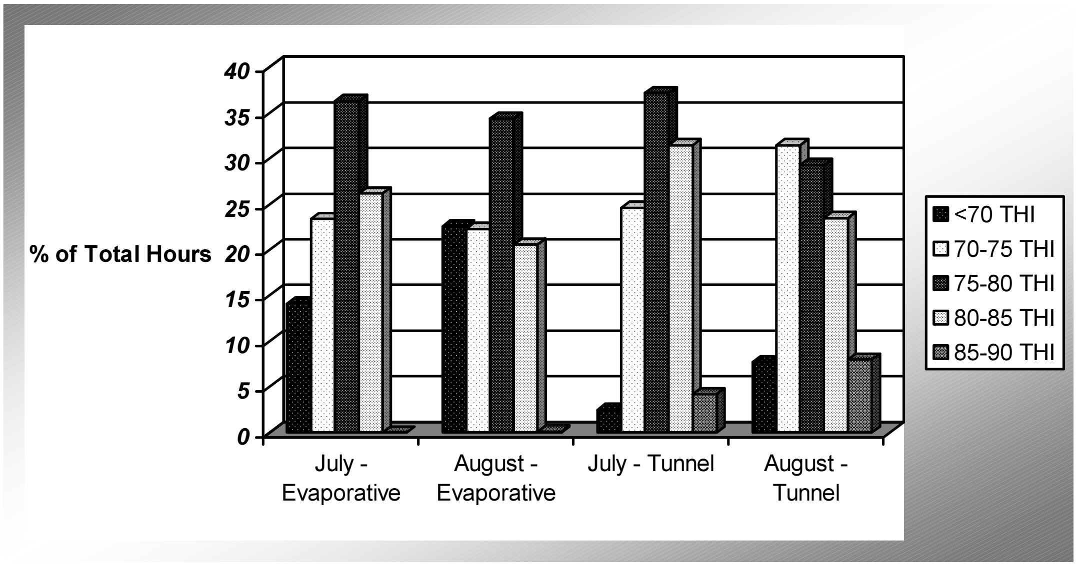


Figure 6. Percentage of hours at different levels of temperature-humidity index of tunnel ventilated tie stall barns with and without evaporative cooling during the hours of 1:00 pm to 8:00 pm during July and August of 2001.