# Effect of Tunnel Ventilation and Evaporative Cooling on the Barn Environment and Cow Comfort in Midwest Dairy Facilities

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**Introduction**

Heat stress during the summer months reduces milk production and reproductive efficiency. Cows are beginning to be stressed when the temperature humidity index (THI) exceeds 72 (Armstrong, 1994). Others have suggested (Hahn, et al., 1992) that feed intake of cattle will be reduced when temperatures exceed 75 °F. Dairy cattle produce large amounts of heat from both ruminal fermentation and metabolic processes. As production increases, the total amount of heat produced increases. In order to maintain body temperature within the normal range, cows must exchange this heat with the environment. This exchange primarily occurs via the lungs and moisture evaporation from the skin under heat stress conditions. Under natural conditions and at temperatures below 60 °F, more than 50% of the heat is lost by non-evaporative cooling (Figure 1). As the temperature reaches 80 °F, only about 25% of the heat is lost through non-evaporative methods and 75% is lost via moisture evaporation from the skin and the lungs. As temperature continues to increase above 80 °F, a greater percentage of heat is lost via the skin and lungs and a much smaller portion through non-evaporative methods (Kibler, 1950).

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. 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.

**Recent Studies**

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 (Figures 4 and 5). 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 presented in figure 4 indicates 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 air flow of 500-600 ft/sec and a small cross-sectional area. The other barn (figure 5) 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 effect 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 1). The reduction in hours above a THI of 75 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 2). 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.

Changes in barn environment for evaporative cooled and tunnel ventilated barns are shown in Figures 6, 7 and 8. 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 9) 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.

Data presented in Figure 10 suggests that micro environments are present in large tunnel ventilated and evaporative cooled freestall barns. The coolest and highest relative humidity air was present near the inlet. As the distance from the inlet increased temperature increased and relative humidity decreased. Depending upon the time period of the day, a 3-5 ºF increase in temperature was observed from the inlet to the exhaust. In large tunnel ventilated and evaporative cooled barns, there may be an advantage to having higher producing animals in the pens closest to the inlet and evaporative pads.

**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.

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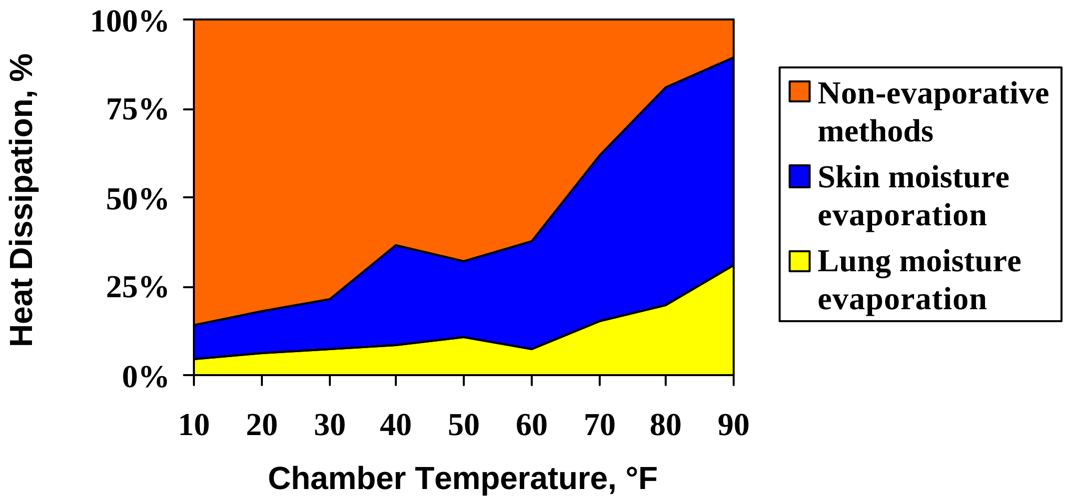
**Figure 1.** Methods of heat dissipation by dairy cattle at different environmental temperatures.




Kibler, H.H., 1950.

**Figure 2.** Potential air temperature change due to evaporative cooling at various levels of ambient air temperatures and relative humidity.

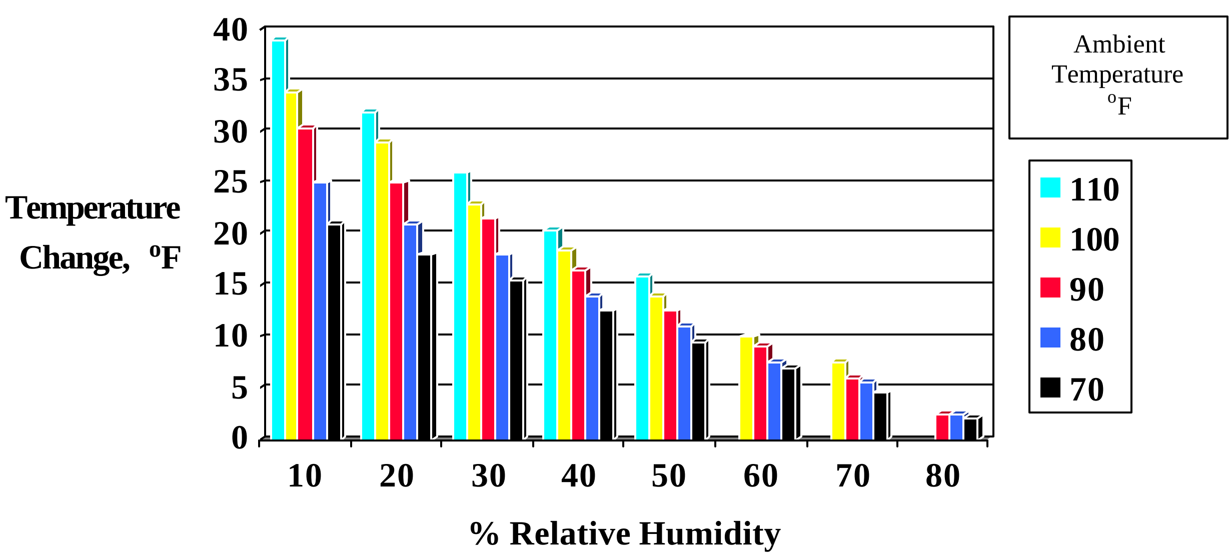


**Figure 3.** Potential temperature-humidity index change due to evaporative cooling at various levels of ambient air temperature and relative humidity.

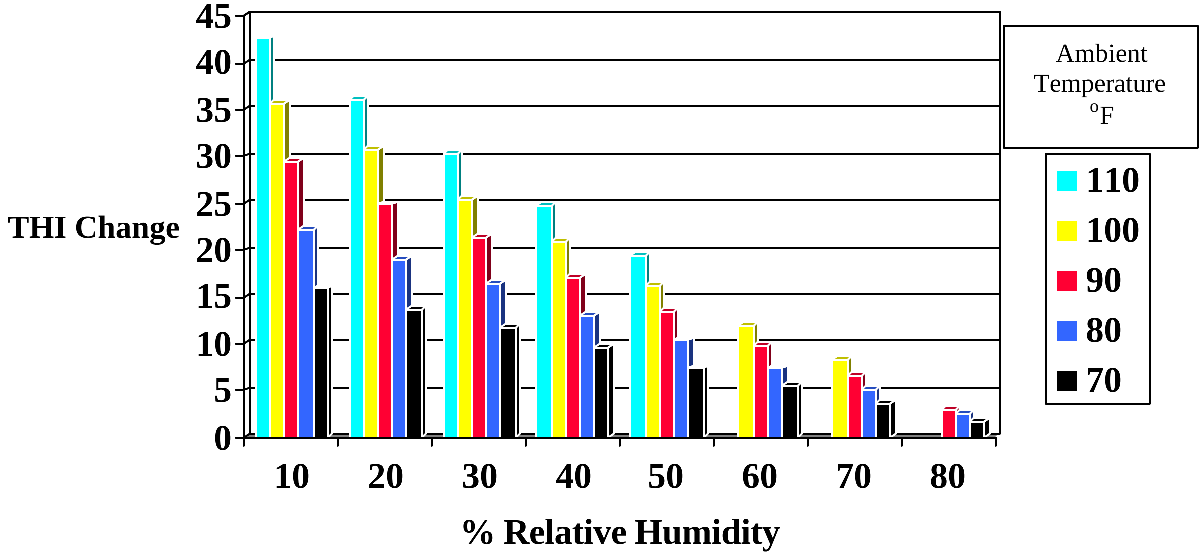
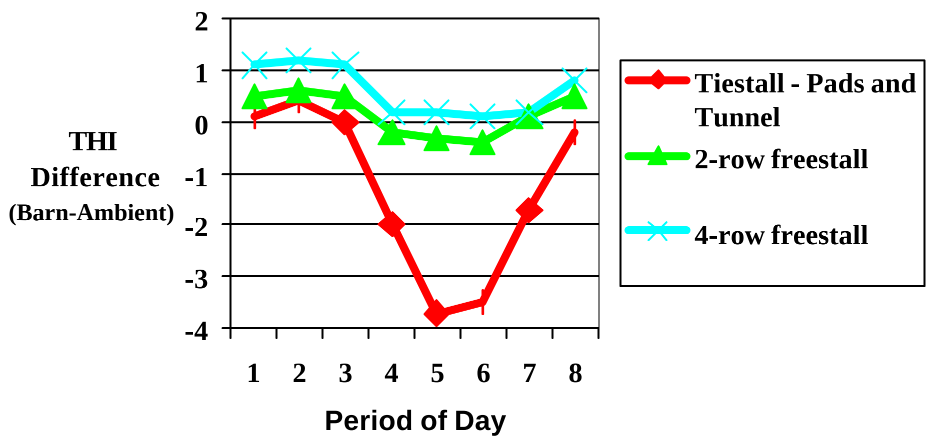
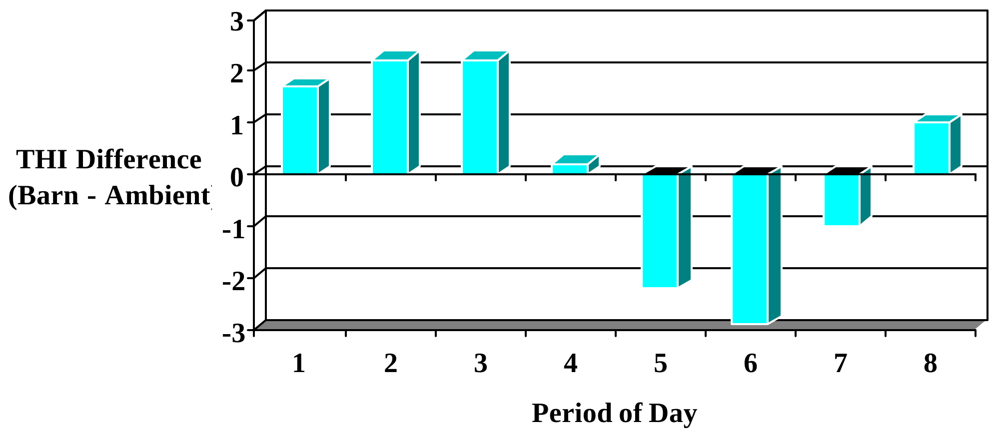



**Figure 4.** Effect of cooling system and barn style of the difference between barn and ambient THI at different periods* of the day during summer heat stress**.




*Period 1=12:00 am -3:00 am, 2=3:00-6:00 am, 3=6:00 am-9:00 am, 4=9:00 am-12:00 pm, 5=12:00 pm -3:00 pm, 6=3:00 pm – 6:00 pm, 7=6:00 pm – 9:00 pm, 8= 9:00 pm – 12:00 am
**July 6 – September 6, 2000.

**Figure 5.** Difference between barn and ambient conditions at different periods* of the day of a tunnel ventilated and evaporative cooled freestall barn during summer heat stress**.




*Period 1=12:00 am -3:00 am, 2=3:00-6:00 am, 3=6:00 am-9:00 am, 4=9:00 am-12:00 pm, 5=12:00 pm -3:00 pm, 6=3:00 pm – 6:00 pm, 7=6:00 pm – 9:00 pm, 8= 9:00 pm – 12:00 am
**July 11 – September 11, 2000.

**Figure 6.** Effect of evaporative cooling on temperature difference (barn-ambient) during three different periods of the day in tie stall barns during the summer of 2001.

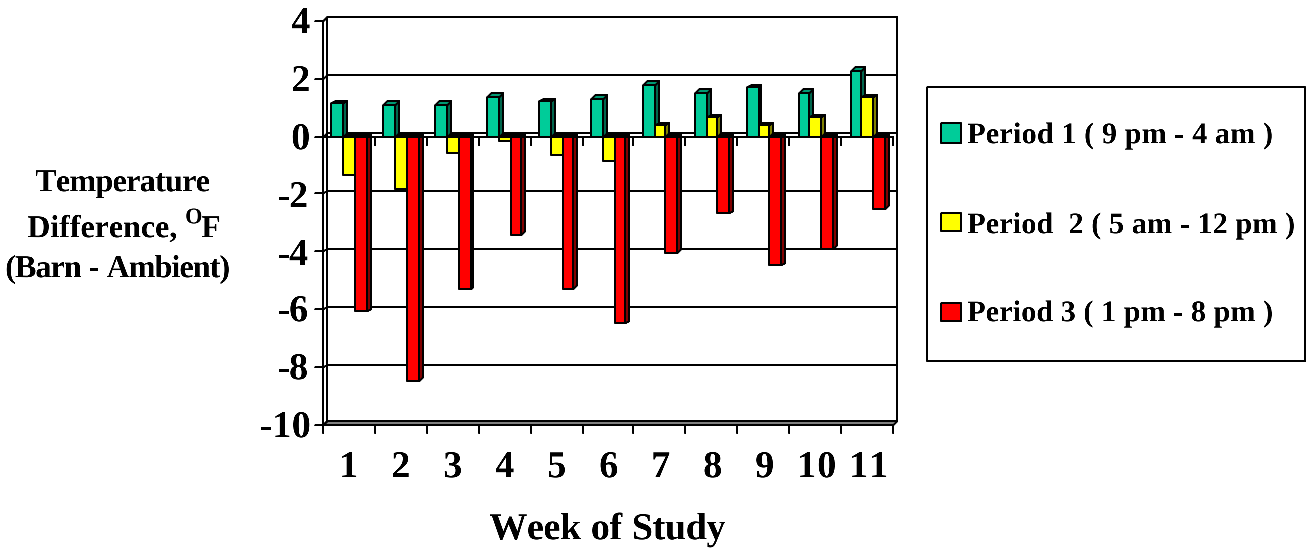


**Figure 7.** Effect of evaporative cooling on relative humidity difference (barn-ambient) during three different periods of the day in tie stall barns during the summer of 2001.

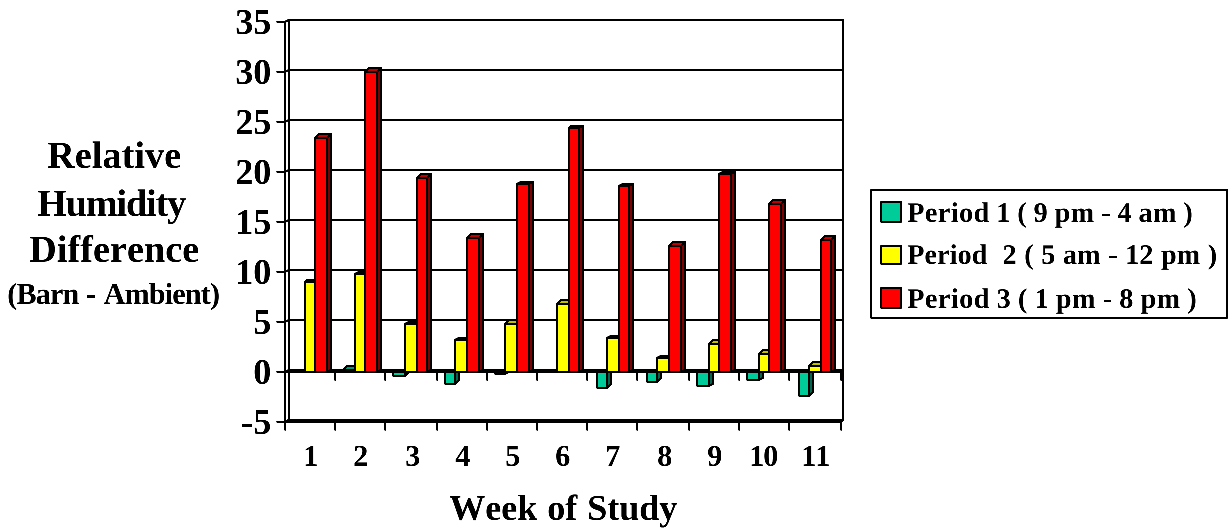



**Figure 8.** Effect of evaporative cooling on temperature-humidity index difference (barn-ambient) during three different period of the day in tie stall barns during the summer of 2001.

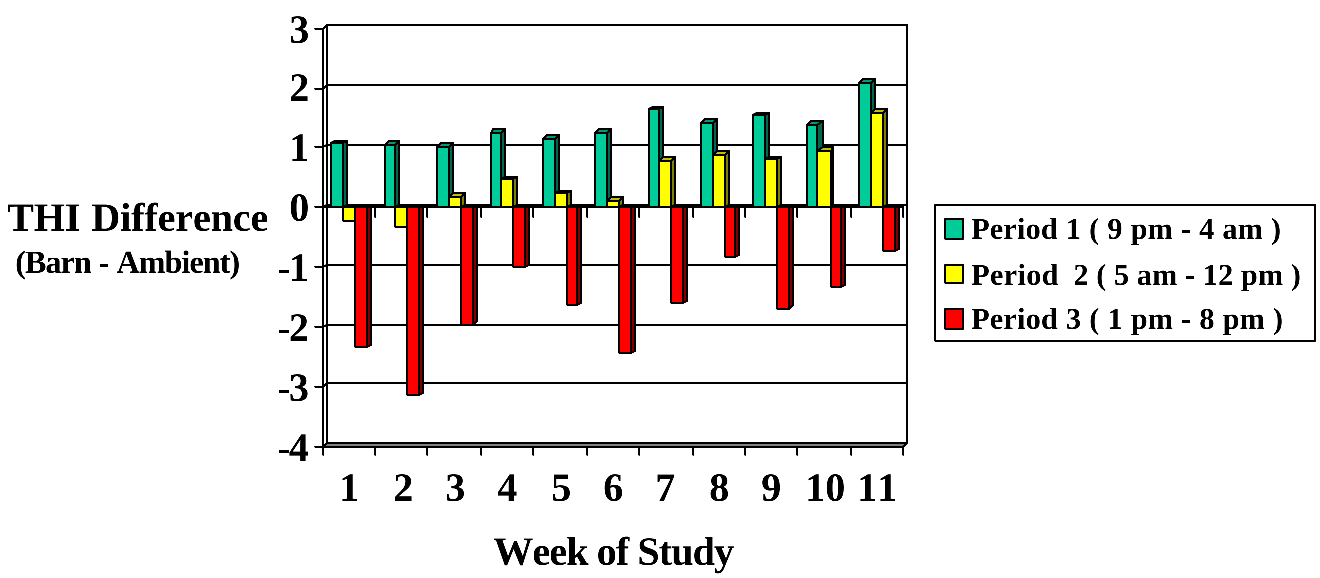


**Figure 9.** Percentage of hours at different levels of temperature-humidity index of tunnel ventilated tie stall barns with and without evaporative cooling during the hours of 1:00 pm to 8:00 pm during July and August of 2001.

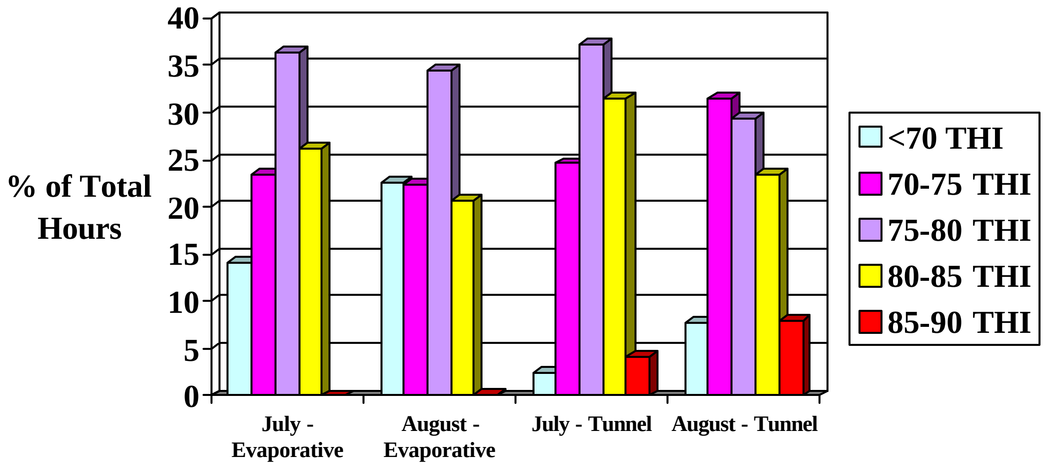
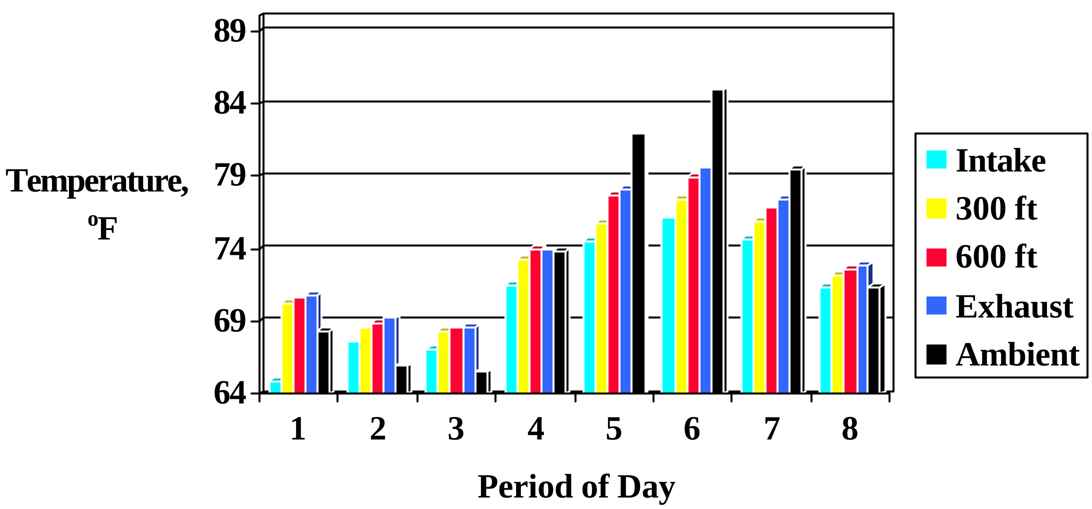



**Figure 10.** Effect of location on temperature in a tunnel ventilated and evaporative cooled dairy freestall barn.




Data collected from July 11 to September 11, 2000.
Period = 3 hour blocks of time starting at midnight.

**Table 1.** Effect of evaporative cooling on the percent of summer hours below and above Temperature-humidity index (THI) of 75 in four Midwest dairy facilities.

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

**Table 2.** 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, ºF | 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, ºF | 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, ºF | 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, ºF | 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.