Heat Stress Management In Freestall Barns In The Western U.S.

By D.V. Armstrong, University of Arizona
P.E. Hillman, Cornell University
M.J. Meyer, Kansas State University
J.F. Smith, Kansas State University
S.R. Stokes4 and J.P. Harner III

Heat Stress Management In Freestall Barns In The Western U.S.

Milk production and reproduction efficiency is reduced by heat stress in dairy cows caused by high temperature with or without high humidity. As daily milk production per cow increases into the 100+ range the problem of heat stress will become even greater.

Various cooling systems have been evaluated for cooling cattle in both high, moderate and low humidity areas of the U.S. (Armstrong, 1994; Bray et al., 1994; Igono et al., 1987; Lin et al., 1998; Strickland et al., 1989; Turner et al., 1992). These research trials have improved milk production in cows experiencing heat stress, with results varying from 3-14 lb of milk per day. The systems vary from using large droplets of water (spray) to soak the hair coat and wet the skin of the cow and using forced air movement across the body of the cow, or using small water droplets to cool the air, as the droplets evaporate, the animal is cooled when the cooled air is blown over the cow's body and also when the cooled air is inhaled. The successes of those systems are influenced by humidity and wind velocity.

Cooling cattle under shades in open corrals which are typically used in medium humidity climates have had success with spray and fan systems using water pressure of 120-250 P.S.I. to minimize the ground wetting. In Israel, Flamenbaum et al. (1986) used an alternating water-air system over a concrete floor. Similar systems used in Florida (Bray, 1994) cooling cows in the free stall caused excess water, causing wet floors and wet free stalls which increases mastitis and foot and leg problems.

Most of the freestall barn cooling trials, Turner et al. (1998), Bray et al. (1994), Strickland et al. (1989), and Igono et al. (1989) have been more successful in cooling cattle in the feed line area than cooling the cow in the bedded freestall. Milk production was increased 4.6 lb of milk per day and feed intake increased 2.8 lb per day when cows were cooled in the feed passage by alternating water for 1.5 minutes and running fans for 13.5 minutes every 15 minutes when compared to no cooling (Strickland et al., 1989). In a similar trial in Missouri by Igono et al. (1987) milk production was increased with a spray and fan system over the feed lane by 4.4 lb when compared to shade only.

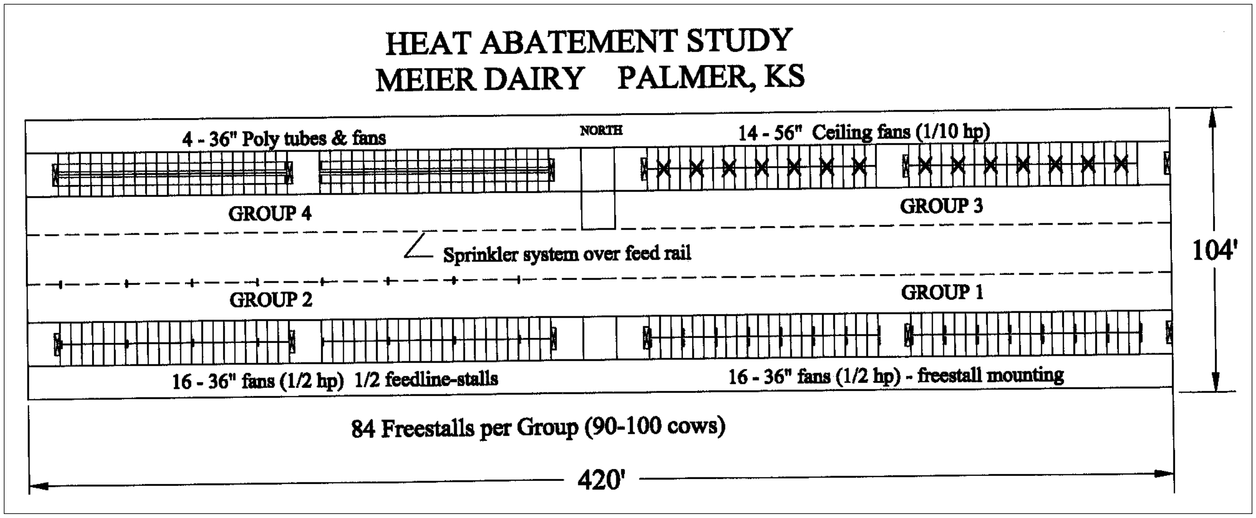
Lin et al. (1997) in Alabama, tested three cooling systems to no cooling. Their cooling systems were (1) sprinklers over the feed lane plus misters over the freestalls; (2) sprinklers only over the feed lane; (3) misters only over the freestalls; (4) no water cooling. Fans were used with each system. Milk production per day was the highest with the treatment with water cooling over both the feed lane and freestalls (52 lb) and lowest with no water cooling (46.7 lb), and the same with the other two treatments at 48.6 lb.

In an experiment to determine water use necessary to cool cows, Means et al. (1992) showed no difference in milk production between three cooling systems with a water application rate of 83, 130 or 186 gal of water per hour. Although Turner (1998) in Kentucky did not report milk production, this experiment with a fan and high-pressure mist cooling system was effective in decreasing the air temperature in a freestall barn by 2-7 F during the warmest part of the day.

In a 1985 trial by Berman et al. in Israel using fans only, air movement only was used to lower

Table 1: Kansas Barns – Period Assignments.

period	time	period	time
1	12am-2:59am	5	12pm-2:59pm
2	3am-5:59am	6	3pm-5:59pm
3	6am-8:59am	7	6pm-8:59pm
4	9am-11:59am	8	9pm-11:59pm



the cows' body temperatures during periods of high ambient temperature. Bray et al., in 1994, reported that increasing the air velocity to 7-10 ft/sec will improve evaporation on the surface (skin) area of dairy cattle, thus improving cooling efficiency.

Although there is less information in the literature on roof design, material and height than cooling systems for freestall barns in hot climates, Stowell et al. (1998) reported that there was no difference in four row freestall barns with a 4:12, 33% and orientation of north-south vs east-west in Michigan to environmental temperatures at the cow level. Natural ventilation from wind played a substantial role in the heating of the surface; when more wind occurs there is less heat. These Michigan barns had an eave height of 10-11.75 feet and a roof slope of 4:12 (33%).

Neubauer and Cramer (1965) tested several shade materials and orientations and found that roofs with steeper slopes and more exposure to the north had the least daytime heat gain, but they did not measure the temperature at the cow level. Eave height also has been reported to have an effect on environmental temperatures at the cow level. Bray et al. (1990) reported that a barn with an eave height of 10 feet had higher temperatures at the cow level than barns at 12-16 feet eave heights.

Roof coating, insulated roofs and water sprinkling also have been used with mixed results. In general, if the eave height is above 10 feet and with adequate slope 3-12 (25%) or 4-12 (33%) there is less effect by sprinkling the roof (Buffington et al., 1983). This paper also reported no difference in air temperature at the cow level in a building with a 12-ft. eave height and using 2 inches of styrofoam insulation material. Bucklin et al. (1993) reported no benefit in block globe temperature at the animal level with different roof coatings in a high (16 ft) open shade.

Procedures – Study #1: 2-Row vs 4-Row Barns

The thermal temperature of four freestall barns on three farms were measured during July-August

Table 2: Kansas Barns – Period Mean Temperature & Temperature Standard Deviation For 2-Row and 4-Row Barns at Locations 2 & 3, Respectively.

period	month	4-row (ºF)	mean SD	2-row (ºF)	Mean SD
1	July	74.7	0.84	74.4	0.86
2	July	72.4	0.92	72.0	0.98
3	July	72.8	1.49	71.4	0.80
4	July	78.7	2.02	76.2	2.21
5	July	84.0	1.42	81.9	1.52
6	July	85.4	0.82	84.4	0.98
7	July	82.9	1.74	83.8	1.09
8	July	77.0	1.19	78.0	2.25
1	August	72.5	0.99	72.6	0.97
2	August	70.1	0.74	69.9	1.03
3	August	70.6	1.89	69.1	0.87
4	August	78.8	2.75	75.5	3.16
5	August	84.8	1.31	83.0	1.66
6	August	86.9	0.74	86.1	0.79
7	August	82.2	2.90	84.5	1.92
8	August	75.3	1.12	76.2	1.82

1998 in a study in Kansas. One 2-row barn and one 4-row barn at location one were compared, one 4-row at location three and one 2-row at location two were compared. Location two was 5 miles east at location three. The 2-row barns on each farm were the same mono slope design, with a 12-ft eave height, 2-in-12 roof slope. The 4-row barns had a 13-ft. eave height, 4-in-12 roof slope, and a 30-inch ridge opening at location A and a 20-inch ridge opening at location B. A low-pressure sprinkler system was located over the feed line in all four barns. The 2-row barn at location two utilized 48-inch fans at a 44-foot interval directed over the freestalls. The 4-row barn at location three was divided into 4 pens, each with a different fan system (Figure 1). At location one the 2-row barn used 36-inch fans at 60- and 40-ft intervals directed over the freestalls and the 4-row barn utilized 36-inch fans also at 40-ft intervals over the freestalls. Temperature data was collected in 24-hour periods divided into eight 3-hour periods described in Table 1.

Study #2: Evaluation of Barn Design and Cooling Systems

The purpose of study #2 was to evaluate different cooling systems dairy owners had installed to reduce heat stress. In the summer of 1998 data was collected on 41 freestall barns in California and Texas. Information was collected on barn design, including orientation, eave height and roof slope. In the 41 barns, there were 30 different cooling systems, several roof designs, and 14 barns with no cooling systems. The groups with no cooling systems were used for controls on the same farm or a closely related farm.

Data was collected from 8:30 a.m. to 5:00 p.m. but varied on farms because the equipment and instruments were set up on more than one farm each day, which required travel from one farm to a second and third farm throughout the day to record data. On each farm a set of temperature and humidity recorders were placed to record an ambient temperature and humidity for the day of test. On several farms data was collected continuously for 30-35 days and averaged.

Two methods were used to collect humidity and temperature data. The first method was to place temperature and humidity data loggers above the freestalls, on an outside post and above the feed manger. The height of these recorders was approximately 7 feet above the ground or as near to cow height where the cow could not lick or otherwise influence the data. In the second procedure, a string of (numbers) temperature-humidity sensors were hung from the outside post to a feed line post at approximately 7 feet above the cow. The distance between the sensors was three feet.

Twice a day, at approximately 9-11 and 2-3:30, a telescoping pole used by power companies with the capability of reaching 30 feet in the air was used to measure temperature. A sensor was placed on the end of the pole, and temperature was recorded at 6-8 inches below the roof, near the highest point of the roof or where the air vent or ridge opening occurred. Temperature was also taken at 15 feet and 8 feet above the ground. These measurements were made in the feed alley of the freestall barn just above the feed line.

Wind velocity was also measured at different locations in the barn. This method was difficult to attain a true wind speed in the barn because of variations in natural wind, fan rotations and distances between fans.

Respiration rates were taken on a random sample of 10 cows in each treatment at 10-11:30 a.m. and at 2-3:30 p.m. Pens of cows selected in this trial would vary from 60-150 days in milk but were usually the high producing pens on the dairy farm.

Table 3: Kansas Barns – Period Mean Temperature & Temperature Standard Deviation For Location1.

period	month	4-row (ºF)	mean SD	2-row (ºF)	Mean SD
1	August	74.4	1.10	73.6	1.03
2	August	71.5	0.91	70.6	0.91
3	August	70.6	1.02	70.2	1.01
4	August	79.6	1.01	79.4	0.96
5	August	88.8	1.10	88.4	1.03
6	August	92.6	1.06	92.4	0.95
7	August	89.1	0.97	89.2	0.97
8	August	79.0	4.16	78.3	4.14

Data Interpretation

The information presented in this paper is the data collected on commercial dairy farms. Due to the nature of this study, statistical analysis was not performed.

Results –
Study #1: 2-Row vs 4-Row Barns

In the Kansas trial, barn temperature was compared in two 2-row and two 4-row barns. The temperature data was collected 24-hours a day and divided into eight three-hour periods (Table 1). Mean temperatures of the different barns are presented in Tables 2 and 3. Graphical representations of the period temperatures are also provided (Figures 2, 3, and 4).

Both barn designs reached maximum temperatures during period 6 (3:00 p.m. to 5:59 p.m.) and reached minimum temperatures between periods 2 and 3 (3:00 a.m. to 8:59 a.m.). The temperature in the 4-row barns increased more rapidly than the 2-row barns. This trend was more dramatic at locations 2 and 3. During period 6 (3:00 p.m. to 5:59 p.m.) the maximum temperatures was only slightly higher in the 4-row barns (.2-1 F). The 24-hour heating and cooling trends were similar during July and August at location 2 and 3, with the low mean temperature between periods 2 and 3 (3:00 a.m. to 8:59 a.m.) and the high mean temperature during period 6 (3:00 p.m. to 5:59 p.m.).

The 2-row barn tended to be warmer than the 4-row barns during periods 7 and 8 (6:00 p.m. to 11:59 p.m.) at location 2 and 3 and during period 7 (6:00 p.m. to 8:59 p.m.) at location 1. This is most likely due to the temperature loggers being in the direct sun of early evening hours.

In summary, the temperature in 4-row barns increased more rapidly and reached a higher mean temperature (3.3-1.8F) than the 2-row barns during periods 4 and 5 (9:00 a.m. to 5:59 p.m.). However, the maximum temperature in 4-row barns was only slightly higher (.2-1F). While it is unknown exactly how a lactating cow responds to these few degrees, it can be speculated that the effect could be minimal.

Figure 2. Period Mean Temperature in July for Location A

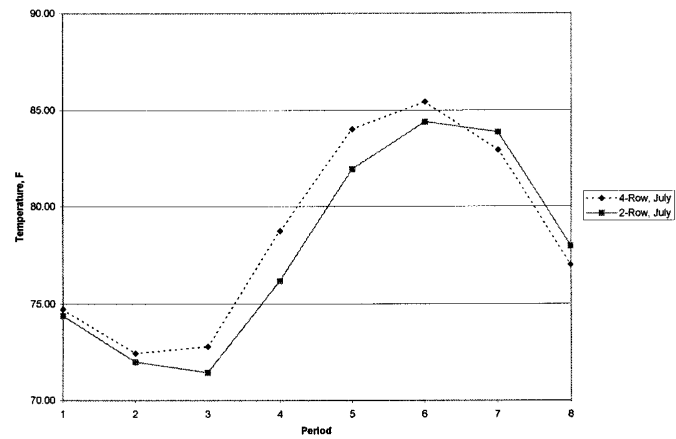


Figure 3. Period Mean Temperature in August for Location A

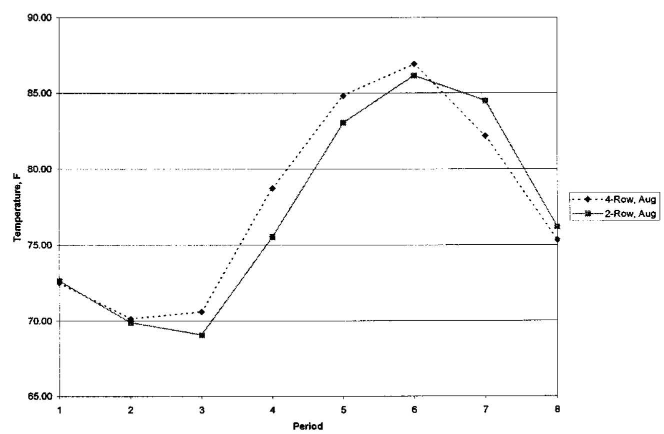
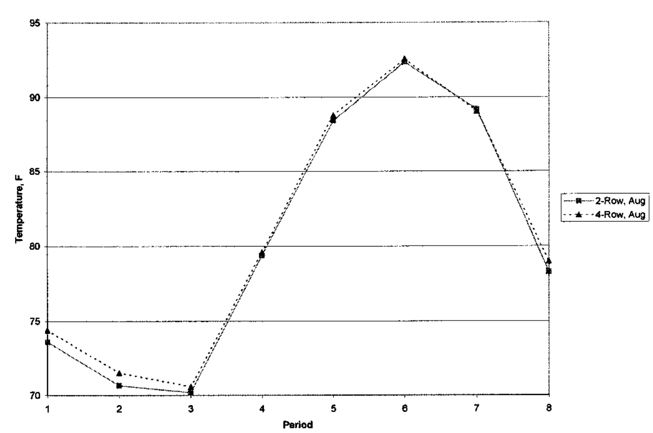


Figure 4. Period Mean Temperature in August for Location B



Study #2: Roof Design

The barn designs observed in this study in California and Texas consisted of two different designs. A gable design (Figure 5) with an opening in the peak and a design developed in California with two openings and a second roof cap (Figure 6). A comparison between the two barn designs and different roof designs was made by comparing the percent increase in respiration rate for 10 cows from the a.m. (morning) to p.m. (afternoon) to evaluate cow comfort in uncooled freestall barns.

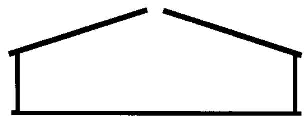


Figure 5. Conventional Design

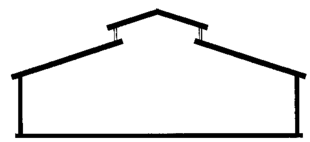


Figure 6. California Design

In the gable design, the roof slope of these barns ranged from 2 in 12 to 4 in 12. The percent increase in respiration rate between morning and afternoon was 2.5% with a 4 in 12 roof slopes and 10.5% increase in the 2-3 in 12 roof slopes. This would suggest that the natural ventilation is greater in roofs with a steeper slope (Table 4). The same results were found with the California roof design between a 3 in 12 when compared to a 2.5 in 12. This data would indicate an advantage in natural ventilation for the gable roof design.

Changes in respiration rate from morning to afternoon were used to evaluate eave-height. Eave-heights were divided into 3 groups; 14 feet or greater, 13-12 feet, and 11 feet or less. The barns with an eave height greater than 14 feet had less of an increase in respiration rate (17.8%) than barns with an eave height of 13-12 feet (31.5%) and 11 feet or less (24.5%) (Table 4). This data would be in agreement with a Florida report by Bray et al., 1990 that barns with a 10 foot eave height had higher temperatures at cow level than barns with a 12-16 foot eave height.

The center opening in the gable roofs were either 28 or 30 inches; therefore, no comparison was made as to the effect of openings for ventilation. In the California barn design there was no difference in the percent change in respiration rate when increased from 24 inches to 30 inches in the two openings. Although when comparing all gable roofed barns to the California design barn there is a large difference in respiration rate increase (7.3% vs 30.3%), which indicates less natural air movement.

A further comparison of the gable roof design and the California roof design was made by comparing the ambient temperature, relative humidity, and temperature humidity index (THI) at 3:00 p.m. with the same climate measurements under the roof of uncooled freestall barns at an approximately 7 ft height over the freestalls. This date (Table 5) would suggest that although the differences are small, the gable roof design has more natural ventilation.

The orientation of the barns to take advantage of prevailing winds also was considered to see if there was an influence on barns which are uncooled or do not have artificial air movement by utilizing fans. The prevailing wind in July-August, 1998, in the central valley of California was predominantly from the southwest

Table 4: Effect Of Roof Design On Respiration Rate Percent Increase From AM to PM In Cows Housed In Non-Cooled Barn.

roof slope	#of barns	increase in resp. rate
4/12 gable	2	2.5%
2-3/12 gable	3	10.5%
3/12 California design	3	25.7%
eave height		
14' or more	6	17.8%
13'-12'	4	31.5%
11' or less	3	24.5%
size of opening for ventilation in roof (California design)		
30"	4	33.5%
24"	4	27.0%

Table 5: Inside barn temperature; relative humidity; and temperature humidity index (THI) vs. ambient temperature change of different barn designs at 3 p.m.

	conventional	California
THI	+0.05	+0.27
temp. ºF	-0.40	-0.01
rel. humidity	+1.60	+3.37

in the morning (a.m.) And shifts to the northwest in the afternoon (p.m.). Weather data from the Visalia-Fresno Airport authorities indicated this wind varies from 5-9 m.p.h. in the summer months.

Although the sample of barns was small (9) for uncooled barns in central California (Table 6), percent change in respiration rate was slightly higher for the east-west orientation, but the change in east-west barn THI, F, and relative humidity (RH) when compared to ambient weather data at 3:00 p.m. would indicate very small differences. Therefore, one could conclude that orientation of freestall barns in the central valley of California to take advantage of prevailing winds is not an important issue. This would be in agreement with Stovell et al., 1998, who reported that in Michigan there was no difference in temperature at the cow level between north-south and east-west barns. Sun line and shade in the freestall area is probably a more important issue. freestalls on the west side of barns of a north-south orientation, especially with high eave heights, will have sunlight and direct radiation on the cow after 3:00 p.m. when the heat stress is usually at its greatest magnitude.

Table 6: Barn Orientation Influence On Cow Comfort.

	increase in respiration rate between AM and PM
East-West	29%
North-South	22%

inside barn temperature; relative humidity; and THI vs. ambient temperature change at 3 PM

	^{0}F	rel. humidity	THI
East-West	0.0	2.3	0.2
North-South	-0.2	3.5	0.4

Study #2: Cooling Systems

The cooling systems compared in this study can be grouped into four systems: (1) spray and fans, (2) feed line spray, (3) spray and orchard fans, and (4) high pressure foggers. Although within a system there is some variation, a general description of each system is as follows:

1. Spray and fan consists of a 36-48 inch fan placed on the roof support post just above the feed line with a mister kit. The fan spacing is usually 20-24 feet, although up to 40 has been used. The air is directed toward the free stalls at an angle of 40-50 degrees and downward 15-25 degrees. Fans are usually mounted at 7-9 feet from the bottom of the fan to the ground. A few installations were mounted on the outside post, blowing toward the stalls, and some have been installed above the freestalls. Some of these systems also have feed line spray.

2. Feed line spray. The spray line is placed either on the feed line or behind the cow at the feed line at 6-9 feet in height. Distance between nozzles vary from 4-9 feet depending upon the nozzle selected, water pressure usually is from 65-200 P.S.I. There are no fans utilized in this system.

3. Spray and Orchard Fan. A fan with two 6 foot blades is mounted every 75-125 feet above the feed alley. The fan rotates approximately 150 degrees every 40 second. A spray nozzle displaces water as the fan rotates. Some of these systems also include feed line spray.

4. High Pressure Foggers. This system consists of nozzles in a line placed above the freestalls and near the feed line at approximately 8-9 feet high. The pressure varies in each system from 800-900 P.S.I. Because the water droplets are so small, curtains are placed on the side of the barn where the prevailing wind is from. This keeps the mist in the area where the cow is lying or standing.

Using the data from Table 7, which compares the percent increase in respiration rates from a.m. to p.m. for the different cooling systems and non-cooled barns, there is a difference in cooling systems on cow comfort as measured by respiration rates. The most effective cooling system was the

Table 7: Percent Increase In Respiration Rate From AM to PM For Cooling Systems and Non-Cooled Barns.

type of cooling	# barns	% increase*	range of change
no cooling	14	23%	3-52
spray and fan	19	14%	0-34
feedline spray	6	18%	4-36
spray and orchard fan	3	10%	2-17
high pressure foggers	2	41%	32-50

spray and fan system, followed by the orchard fan system and the feed line spray only system. The high pressure fogger system showed the poorest results for cow comfort. The range within each system except the high pressure foggers demonstrate that each system is capable of effective cooling, depending upon installation.

When breaking down the description of each system even with more detail would indicate that those systems which had the lowest number for percent increase in respiration rate for spray and fan and feed line spray only also had installed the system closer to the cow. Those systems which utilize the spray and fan cooling system with direct spray and a high velocity of air movement across the cow's body surface are the most effect cooling systems. One orchard fan had a double nozzle system with twice the water volume was more effective than the other two installations. The high pressure fog system has a disadvantage, as any air movement is minimal across the surface of the cow. When fresh air is brought into the barn by raising the curtain, the very small water droplets were dissipated or went through the vents in the top of the barn.

Table 8, which compares the change from ambient temperature, percent RH, and THI for the different cooling systems and non-cooled barns shows that there is little change in the measurements except for the high pressure fogger systems which had a 34.9% increase in RH, a 4∞F lower temperature, but an increase in the THI.

Environmental Conditions That Cool Cows

The THI has traditionally been used to indicate when heat stress will occur. Mild heat stress in high producing cows occurs when THI exceeds 72, and moderate heat stress occurs when THI exceeds 80 (Armstrong 1994). Using this guide, all the cows in this study should have been heat stressed because the afternoon THIs ranged from a low of 75.5 to a high of 83.5. Instead, many cows showed very little increase in respiration rate from morning until afternoon, even when exposed to THIs as high as 82-83 (Figure 1). This apparent discrepancy occurs because THI, when used as an indicator of heat stress for cows, assumes the cows are not being cooled with fans and spray. Exposing cows to forced air cooling along with spray helps keep cows cool even when exposed to high THIs.

Cooling systems had little impact on the measured THI in the barns of this study (Table 8). This alone did not show a correlation with the increase of respiration rate from morning to afternoon (Figure 7). Only high-pressure fogger systems are unique inasmuch as air flow is purposely restricted with the use of curtains to keep the moisture from escaping out the roof vents. As a consequence, air is contained long enough in the air space for it to be cooled by evaporation and its humidity to be increased with vaporization of fine water droplets.

Table 8: Environmental Change From Ambient For Different Cooling Systems.

type of cooling	# barns	THI (change from ambient	ºF	% R.H.
no cooling	14	0.1	-0.3	1.3
spray and fan	19	-0.2	-1.1	2.4
feedline spray	6	0.4	0.3	1.5
spray and orchard fan	3	-0.2	-0.2	2.8
high pressure foggers	2	1.6	-4.0	34.9

Although THI is not a useful indicator of heat stress in freestall barns, wind speed is a useful indicator, as long as the cows are simultaneously cooled with spray (Figure 8). Increasing wind speed alone, without spray, did not appear to reduce the elevation of respiration rate from morning to afternoon.

In summary, one could conclude from this data on 4-row freestall dairy barns that the most effective way to cool dairy cows in freestalls is:

1. Design the barn with a gable roof design with a 4 in 12 roof pitch and 14 ft side walls.
2. Wet the cow body surface by installing the spray system as close to the cow as possible.
3. Combine wetting with higher air flows directly across the body surface of the cow. Only wetting the cow, without increasing air flow, is not sufficient enough to cool the cow.

THI is not a useful indicator of heat stress of typical freestall barns in Texas or California during periods of hot weather. Spray combined with forced air cooling keep cows cool in spite of being exposed to THIs above 75.

(Note: Future studies in the summer of 1999 will be made to determine the amount of water and wind speed necessary for the maximum cooling effect of the cow.)

ACKNOWLEDGMENTS

Funding for this project was provided by Monsanto Dairy business, St. Louis, Missouri and Kansas Dairy Commission. Monsanto sales personnel in Texas and California provided dairy contacts for data collection. Texas Cooperative Extension personnel also provided assistance in data collection on the Texas dairy farms. Texas county agricultural agents include Bob Whitney, Comanche County; Joe Pope, Erath County; and Danny Phillips, Hamilton County.

This project would not have been possible without the cooperation and assistance of dairy farm owners and managers from the following farms:

Texas

Ray Johnston Dairy
David DeJong Dairy
Sun Valley Dairy
Keith Broumley Dairy

Kansas

Dale Klassen Dairy
Meier Dairy Inc.
Robert Ohlde Dairy

California

William deBoer Dairy
J.R. Dairy
Dairyland Farms
Sousa & Sousa Dairy
Rib-Arrow Dairy
Wilbur Brothers Dairy
Northstar Dairy
Oakview Dairy
Felipe C. Ribeiro & Sons Dairy
Hollandia Heifer Ranch
Moonlight Dairy
Vista Livestock Company
Ribeiro Dairy Farm
Foster Farms Dairy
Macy-L Dairy
Emerson Dairy, Inc.
Scheenstra Dairy
Fred A. Douma Dairy
S&S Dairy
Simoes Dairy
Tony de Groot Dairy
Calif. State University-Fresno
Milky Way Dairy
Bacchetti-Silva Dairy

Notes

Figure 7: Increase in respiration rate vs THI. Respiration rates were measured once in the morning and later in the mid afternoon. THI values are the average values for the afternoon.

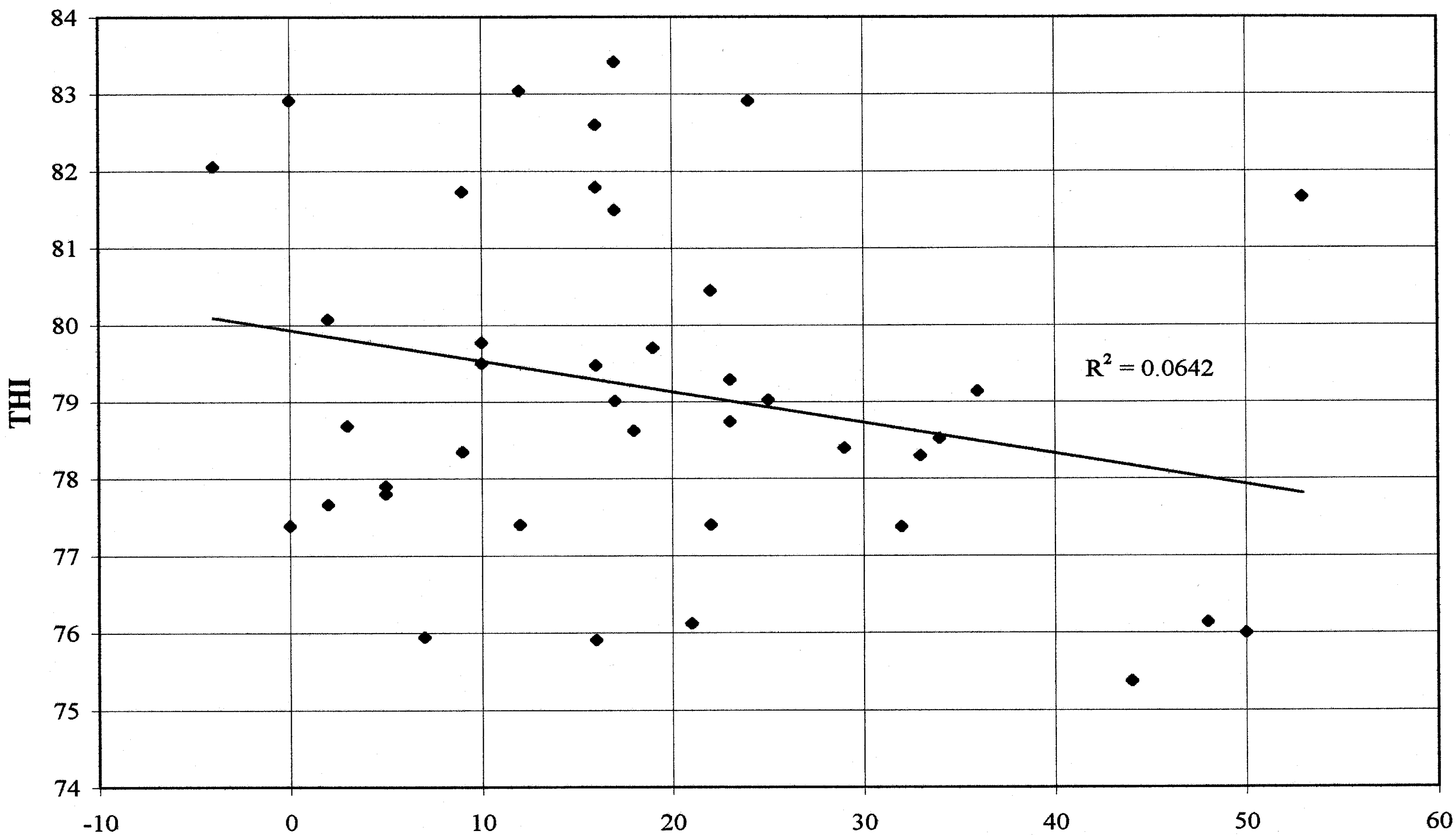


Figure 7. Percent Increase in Respiration Rate from Morning to Afternoon

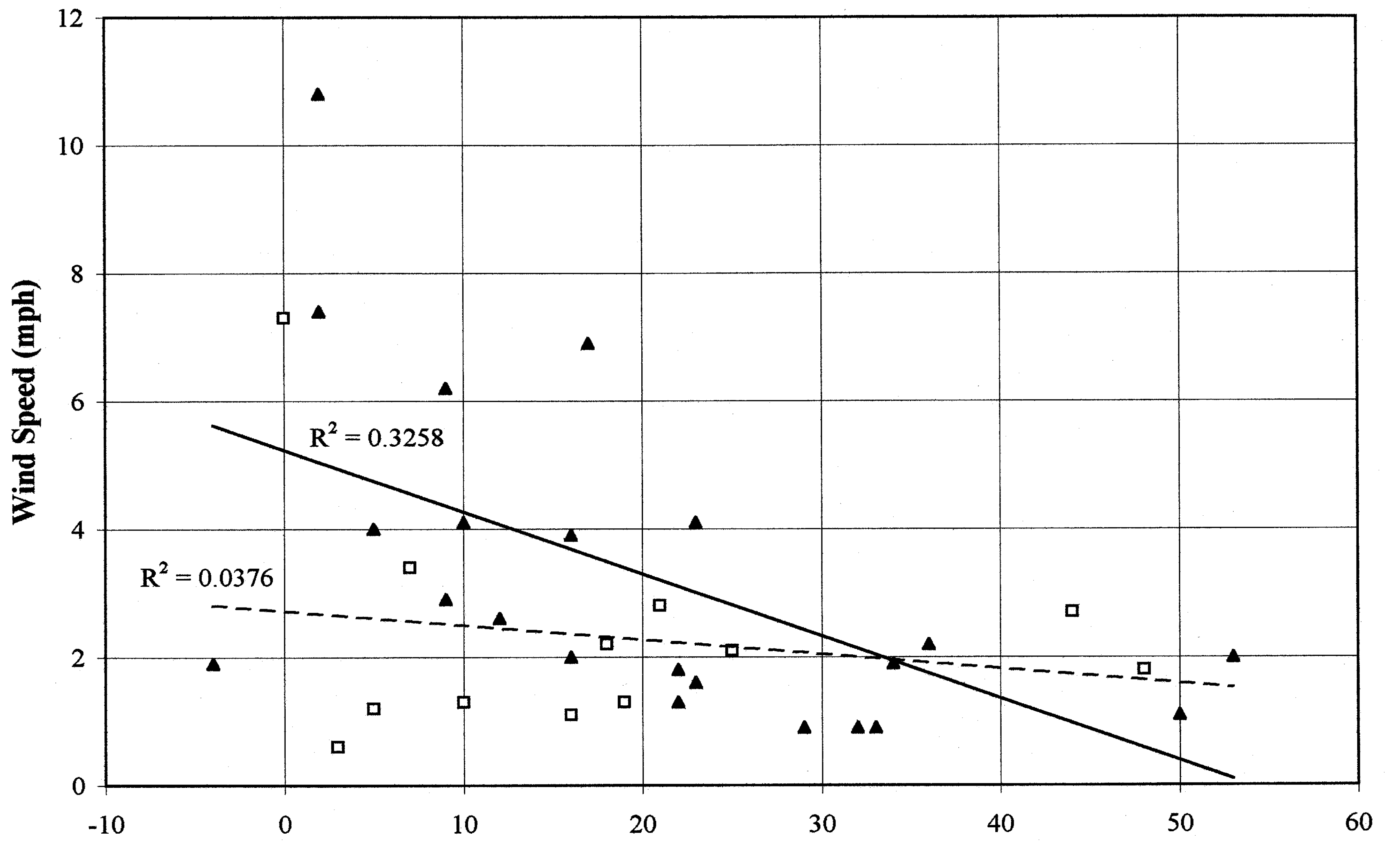


Figure 8. Percent Increase in Respiration Rate from Morning to Afternoon

Figure 8. Increase in respiration rate vs wind speed. Respiration rates were measured once in the morning and later in the mid afternoon. Wind speeds are spot measurements taken at the same time respiration rates were recorded.

References:

1. Armstrong, D.V. 994. Heat stress interaction with shade and cooling. J. Dairy Sci. 77:2044-2050.
2. Berman, A., Y. Folman, M. Karen, M. Mamen, Z. Herz, D. Wolfenson, A. Arieli and Y. Graber. 1985. Upper critical temperatures and forced ventilation effects for high-yielding dairy cows in a subtropical climate. J. Dairy Sci. 68:1488-1495.
3. Bray, D.R., D.K. Beede, M.A. Delorenzo, D. Wolfenson, R.G. Gresig, R.A. Bucklin and S. Means. 1990. Environmental modifications update. Proc. 27th Ann. Florida Dairy Prod. Conf. 100-109.
4. Bray, D.R., R.A. Bucklin, R. Montoya and R. Gresig. 1994. Means to reduce environmental stress on dairy cows in hot, humid environments. Proc. 3rd Internatl. Dairy Housing Conf.: Dairy Systems for the 21st Century. Am. Soc. Agric. Eng., St. Joseph, MI, Feb. 1994.
5. Bray, D.R., R.A. Bucklin, R. Montoya and R. Gresig. 1994. Cooling methods for dairy housing in the southeastern United States. Trans. ASAE, paper no. 94-4501. St. Joseph, MI.
6. Bucklin, R.A., R.W. Bottcher, G.L. Van Wicklin and M. Czarich. 1993. Reflective roof coatings for heat stress relief in livestock and poultry housing. Appl. Eng. Agric. 9(1):123-129.
7. Buffington, D.E., R.J. Collier and G.H. Canton. 1983. Shade management systems to reduce heat stress in hot, humid climates. Trans. ASAE 26(6):1798-1802.
8. Flamenbaum, I., D. Wolfenson, M. Mamen and A. Berman. 1986. Cooling dairy cattle by a combination of sprinkling and forced ventilation and its implementation in the shelter system. J. Dairy Sci. 69:3140-3147.
9. Igono, M.O., H.D. Johnson, B.J. Stevens, G.F. Krause and M.D. Shanklin. 1987. Physiological, productive, and economic benefits of shade spray and fan systems versus shade for Holstein cows during summer heat. J. Dairy Sci. 70:1069-1079.
10. Lin, J.C., B.R. Moss, J.L. Koon, C.A. Flood, S. Rowe, J.R. Martin, B. Brady, F. Degraves and R.C. Smith. 1997. Effect of sprinkling over the feed area and misting free stalls on milk production. Prof. Anim. Scientist 14:102-107.
11. Lin, J.C., B.R. Moss, J.L. Koon, C.A. Flood, R.C. Smith III, K.A. Cummins and D.A. Coleman. 1998. Comparison of various fan, sprinkler, and mister systems in reducing heat stress in dairy cattle. Appl. Eng. Agric. 14(2):177-182.
12. Means, S.L., R.A. Bucklin, R.A. Nordstedt, D.K. Beede, D.R. Bray, C.J. Wilcox, and W.K. Sanchez. 1992. Water application rates for a sprinkler and fan dairy cooling system in hot-humid climates. Appl. Eng. Agric. 8(3):375-379.
13. Neubauer, L.W. and R.D. Cramer. 1965. Shading devices to limit solar heat gain but increase cold sky radiation. Trans. ASAE 8(4):470-472, 475.
14. Stowell, R.R., W.G. Bickert, F.U. Nurnberger. 1998. Radiant heating and thermal environment of medal-roofed dairy barns. Proc. 4th Int'l. Dairy Housing Conf. Am. Soc. Agric. Eng., St. Joseph, MI, 193-200.
15. Strickland, J.T., R.A. Bucklin, R.A. Nordstedt, D.K. Beede and D.R. Bray. 1989. Sprinkler and fan cooling systems for dairy cows in hot, humid climates. Appl. Eng. Agric. 5(2):231-326.
16. Turner, L.W. 1998. Fan and high-pressure mist (fog) systems performance for cooling lactating dairy cows. Proc. 4th Int'l. Dairy Housing Conf., St. Joseph, MI. ASAE 201-208.
17. Turner, L.W., J.P. Chastain, R.W. Hemken, R.S. Gates and W.L. Crist. 1992. Reducing heat stress in dairy cows through sprinkler and fan cooling. Appl. Eng. Agric. 8(2):251-256.

Notes