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Freestall Barn Design and Cooling Systems

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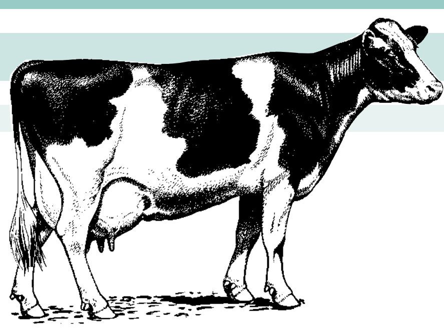


Reducing heat stress in freestall barns should be a major concern for dairy producers and dairy industry advisors. Under modern management systems, lactating dairy cows spend more than 90 percent of the day in the freestall barn. Without effective freestall cooling systems, significant production and reproduction losses will occur. In terms of cow comfort, the effective temperature is a function of air temperature, humidity, air flow and solar radiation. Heat dissipation from the dairy cow at temperatures above 60°F is largely due to evaporative losses from the skin, with a much smaller portion lost via lung cooling (Kibler, 1950.) So the goal of heat stress abatement in freestall barns should be to provide protection from solar radiation and maximize evaporative losses from the skin. Heat dissipation from the skin is increased by increasing air exchange and air flow, and the evaporation of supplemental water applied to the skin.

Barn Orientation

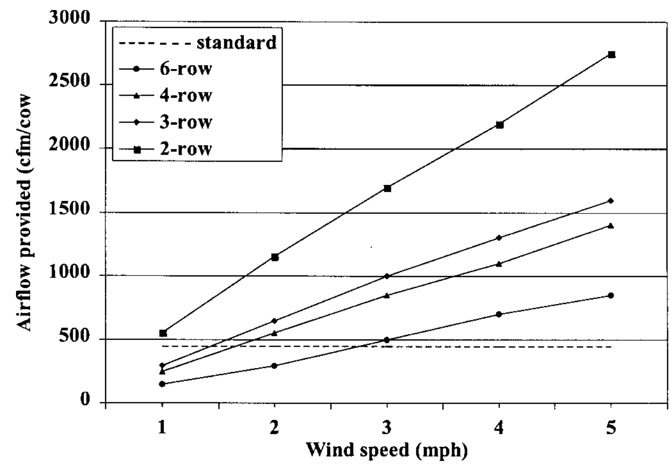
The first freestall barn design criteria to consider should be the orientation of the structure. Barns with a north-south orientation are exposed to greater solar radiation than barns with an east-west orientation. Sunlight enters north-south oriented barns directly in the morning and afternoon. While afternoon sun is the most detrimental, morning sun also can affect cow behavior during hot weather. Because cows seek shade in summer, direct sunlight will reduce stall usage, especially stalls located on outside walls. It is also important to consider that with greater sidewall heights, afternoon sunlight can reach much of the west half of the structure. Protection from direct sunlight is vital for effective heat stress abatement. Barns with an east-west orientation provide greater protection from direct sunlight than those with north-south orientations.

Air Exchange

Ventilation is influenced by sidewall opening, eave opening, building width, ridge opening and wind speed. Mechanical ventilation rates should exceed 470 cfm (cubic feet per minute) per 1,400-pound cow (Bickert, et al., 1997). During the summer, better ventilation can increase water evaporation and skin heat losses. Open sidewalls provide maximum air exchange. In general, open sidewall buildings have ventilation rates that exceed recommendations. Sidewall heights on four-and six-row freestall buildings should be 14 to 16 feet high and a minimum of 75 percent open. However, when trying to achieve maximum water evaporation rates, increased air exchange is important to preventing significant increases in relative humidity inside the barn.

Building size and design can influence ventilation rates. Data presented in Figure 2 demonstrates the effect of building width upon ventilation rates at different wind speeds. As building width increases, greater wind velocities are required to provide adequate ventilation. While, two-row barns may be adequately ventilated with a 1 mph wind, six-row barns require 3 mph wind for adequate ventilation. In addition, stocking rates and available area influence the need for ventilation (Table 1). Heat units produced per square foot of building increase with increased stocking rates. When comparing four and six-row barns, reduced area per cow increases the heat load in six-row barns.

In addition to building width and sidewall height, ridge openings are required to manage heat stress. Armstrong and others (1999) observed higher respiration rates in the afternoon when cows were housed in barns with covered ridges. Ridge openings should be two inches per 10 feet of building width.



Unitized air exchange rates of common barn configurations for low-to-moderate wind speeds (assumes 12-foot sidewall height; 9-foot effective opening height for 2- and 4- row barns, 8 ft. for 3- row 6- row configurations; wind approaches barns at an angle from perpendicular; and 1 cow per row per 4 feet of barn length.

Fig. 2. Building width effect on airflow rates.

Roof slope is another critical design consideration. Heat rises and roof pitch can either enhance or reduce air flow through the ridge opening. In four and six-row buildings, roof slope should be 4/12 to enhance air flow and exchange. Using less slope in these barns has been shown to increase afternoon respiration rates (Armstrong, et al., 1999). Two-row barns with a mono-slope roof often have a 3/12 or 2/12 pitch. This may be adequate considering the narrow width of the building. But two monoslope units built facing each other with only a feed road between is essentially a four-row barn. In this case a 4/12 roof pitch is recommended.

Table 1. Available Feedline Space, Square Footage and Heat Produced by cows in Different Styles of Freestall Barns*

Barn Style	Pen Width (ft)	Pen Length (ft)	# Stalls	Sq. Ft./Cow	Feedline Space	BTU's Cow/hr	Stocking Percentage (cows/stalls)			
							100% BTU's /sq.ft.	110% BTU's /sq.ft.	120% BTU's /sq.ft.	130% BTU's /sq.ft.
4-Row	39	240	100	94	29	4500	48	53	58	63
6-Row	47	240	160	71	18	4500	64	70	77	83
2-Row	39	240	100	94	29	4500	48	53	58	63
3-Row	47	240	160	71	18	4500	64	70	77	83

*Based on a cow weighing 1,500 pounds and producing 70 pounds of milk per day.
(Smith, et al, 2000)

Wind shadow can be a major problem in some cases. In general, to minimize the effect of wind shadow, buildings should be at least 100 feet apart or one and a half times the building width. Any obstruction of natural air flow reduces air exchange. Buildings, equipment and stored forages may all reduce air flow in freestall buildings if adequate separation is not allowed. The most noticeable problem associated with wind shadow is the fact that cattle will seek natural air flow. This results in overcrowding in areas of the barn that are not affected by wind shadow.

Water Location and Requirements

Because water intake increases as temperatures rise, one critical factor in managing heat stress is to provide adequate access to water. It is important to locate a waterer at each crossover with a maximum of 25 stalls between crossovers (100). Crossovers should be 14 feet wide to allow cattle to pass through the crossover while others are drinking. Crossover width is critical to avoid bottlenecks in cow flow. Ideally, two feet of tank perimeter should be provided for each 10 to 20 cows in a pen. In warmer climates, total tank perimeter for a pen is equal to 15 percent of the pen size times two. In addition to enough water space, water flow rates must be adequate to maintain water levels. To meet peak flow demands, well capacity or pumping capacity should be 20 to 30 gallons per 100 cows.

Supplemental Cooling

Freestall barns that are correctly designed will provide maximum natural ventilation. Additional cooling equipment is needed to achieve high levels of milk production. In addition to maintaining high levels of production, heat reduction measures must be cost effective, returning greater profits to dairy producers. Two studies were conducted in 1999 to evaluate different cooling systems in two- and four-row freestall barns located in northeast Kansas.

Four-row Freestall Barn Cooling Systems

Ninety-three multiparous Holstein cows averaging 130 DIM (days in milk) were assigned to one of three cooling treatments. Cows were blocked by lactation number, DIM and production. Cows were housed in one of three identical 100-cow pens on a commercial dairy farm equipped with 84 freestalls per pen (Table 2). The barn was 100 feet wide and 420 feet long. The sidewall height was 12 feet and the roof had a 4/12 slope.

Treatment 1 (2S) was located in the southeast quarter of the building and featured a double row of fans (14- to 36-inch diameter circulation fans with 0.5 horsepower motors) mounted every 24 feet over the freestalls. Each fan had an air delivery rate of 10,000-11,500 cubic feet per minute (cfm) and was angled down at 30 degrees.

Treatment 2 (F and S) was located in the southwest quarter of the building and featured a row of (7-to 36-inch diameter circulation fans with 0.5 horsepower motors mounted over the freestalls. Another row 7- to 36-inch diameter circulation fans with 0.5 horsepower motors) over the cow feedline. Both rows of fans were angled downward at 30 degrees and had the same air delivery rate as those listed above.

Treatment 3 (F and 2S) was located in the northwest quarter of the building with a double row of fans (14- to 36-inch diameter circulation fans with 0.5 horsepower motors mounted every 24 feet over the freestalls and a row of fans (7- to 36-inch diameter circulation fans with 0.5 horsepower motors) mounted over the cow feedline. The angle and air delivery rate was the same as described above.

Each pen was equipped with similar sprinkler systems consisting of 2.5 gallons per minute (gpm) nozzles spaced every 78 inches on center at a height of 8 feet above the headlocks. Sprinklers were on a 15-minute cycle with three minutes on and 12 minutes off. Sprinklers were activated when the temperature exceeded 75° F. The designed application rate was .04 inches per square feet of surface area, which consisted of 12 square feet per headlock or 24-inch feeding space. Total application rate was 50 gallons per cycle.

Fans of all treatments were activated when the temperature climbed above 70° F both day and night.

Initial treatment averages (Table 3) for DIM and milk production were similar for all treatments. Cows cooled with the F and S system produced 4.5 pounds more (P<.05) milk than the 2S system while those under the F and 2S system were intermediate. Dry matter intake was numerically similar for all treatments. All cows increased body condition score during the trial. Cows under the 2S system tended to have a greater increase than than the F and S treatment. This is likely due to similar DMI and lower production for the 2S system.

Four-row Freestall Barn Supplemental Cooling Recommendations

Based on the data presented in Table 3, an effective cooling system for a four-row freestall barn includes fans over both the freestalls and a feedline sprinkling system. Fan spacing should be a maximum of 30 feet for 36-inch, or 40 feet for 48-inch fans, and operate when the temperature reaches 70° F. Feedline sprinkling systems should wet the backs of the cows and then shut off to allow the water to evaporate before beginning another cycle. Sprinklers should operate when the temperature exceeds75° F.

Two-Row Freestall Cooling Systems

In another study 159 Holstein cows were blocked by lactation number, milk production and DIM and assigned to one of three cooling treatments. Cooling systems were assigned to one of three barns with similar dimensions and equipment (Table 4). Each barn contained a single pen with 100 free stalls and 108 cows. One barn (F and S) was equipped with a row of fans (5- to 48-inch diameter circulations fans with 1 horsepower motors) over the freestalls and another row of fans (10- to 36-inch diameter circulation fans with .5 horsepower motors) over the cow feedline. Fans

Table 3. Milk yield, body condition, and feed intake of dairy cows housed in a four-row freestall barn with three different cooling systems.

	Cooling System[1]			
Item	2S	F&S	F&2S	SEM
Initial milk, lb	114.5	115.5	114.8	3.8
Initial days in milk	131	128	131	10.1
Average milk, lb	93.9[a]	98.8[b]	96.5[ab]	2.5
Dry matter intake, lb	55.6	56.2	56.3	-
Change in body condition	+.52	+.39	+.21	.14

[1]2S=two rows of fans over freestalls, F&S=one row of fans over the feedline and one row of fans over the freestalls, F&2S=one row of fans over the feedline and two rows of fans over the freestalls, and SEM= standard error of mean. [ab] Means with uncommon superscript differ (P<0.05) (Brouk, et al., 1999a).

Table 4. Description of buildings and cooling systems installed in two-row freestall buildings.

Building description:

Building type: 2 row

Orientation: East-West (2% slope to west)

Dimensions: width-40 ft, length-220 ft, sidewall height-12 ft, roof slope-2/12

Configuration: 1 pen with 100 stalls per pen and 110 headlocks per pen

Cooling System	F&S	S	S+
SPRINKLERS			
Sprinklers location	feed line	feed line	feed line & north alley
Nozzle rating	25 gph	25 gph	25 gph
Nozzle type	180°	180°	180°
Sprinkler cycle	25 gal/15 minutes	25 gal/15 minutes	35 gal/15 minutes
Sprinkler height	8 ft	8 ft	8 ft
FANS			
Rows over freestalls	1	1	1
Rows over feed line	1	0	0
Number of fans/row stalls	5	5	5
Feedline	10		
Total number of fans	15	5	5
Fan spacing: freestalls	40 ft	40 ft	40 ft
feedline	20 ft		
Fan Diameter & hp:stalls	48 in (1 hp)	48 in (1 hp)	48 in (1 hp)
feedline	36 in (1/2 hp)		
Fan airflow/stall	1,000 cfm/stall	1,000 cfm/stall	1,000 cfm/stall
Fan airflow/headlock	900 cfm/head	0	0

F & S=one row of fans over cow feedline and one row of fans over freestalls, S=one row of fans over freestalls, S+=one row of fans over freestalls and additional sprinkler lines.
(Brouk, et al., 1999b).

Table 5. Milk yield, body condition change, and feed intake of dairy cows housed in a two-row freestall barn equipped with three different cooling systems.

	Cooling System[1]			
Item	F&S	S	S+	SEM
Initial milk, lb	86.9	87.2	88.2	3.5
Initial days in milk	114.6	114.8	114.2	7.28
Average milk, lb	80.8	80.3	79.5	1.7
Dry matter intake, lb	49.9	49.8	49.6	-
Change in body condition	.26	.31	.28	.04

F & S=one row of fans over cow feedline and one row of fans over freestalls, S=one row of fans over freestalls, S+=one row of fans over freestalls and additional sprinkler lines, SEM=standard error of mean.
(Brouk, et al., 1999b).

Table 6. Milk Yield and changes in body condition score of multiparous and primaparous dairy cows housed in two-row freestall barns equipped with three different cooling systems.

	Cooling System[1]							
	Multiparous				Primaparous			
	F&S	S	S+	SEM	F&S	S	S+	SEM
Initial milk, lb	93.1	92.3	93.9	3.0	87.2	88.2	86.9	3.5
Initial days in milk	116.9	118.4	117.9	9.4	112.3	111.2	110.5	11.4
Average milk, lb	81.5	81.6	80.5	2.6	80.0	79.0	79.4	2.7
Change in body condition	+.44	.41	+.27	.06	+.11	+.22	+.25	.07

F&S=one row of fans over cow feedline and one row of fans over freestalls, S=one row of fans over freestalls, S+=one row of fans over freestalls and additional sprinkler lines, SEM=standard error of mean.
(Brouk, et al., 1999b).

were angled down at 30 degrees. Fans over the stalls produced an estimated air flow of 1,000 cfm/stall, and those mounted over the cow feedline produced an estimated air flow of 900 cfm/headlock. Barn two (S) and three (S+) were equipped with a row of fans (5- to 48-inch diameter circulations fans with 1 horsepower motors) over the freestalls and fans were angled as above. Treatments F and S and S both had a similar sprinkler system installed on the cow feedline. The sprinkling system consisted of 2.5 gph nozzles spaced every 78 inches on center mounted at a height of 8 feet on the cow feedline. Sprinklers were on a 15-minute cycle with 3 minutes on and 12 minutes off. Sprinklers were activated when the temperature reached above 75° F. The designed application rate was .04 inches per square feet of surface area which consisted of 12 square feet per headlock or 24-inch feeding space. Total application rate was 25 gallons/cycle. Treatment S+ had a similar sprinkler system to that of F and S and S except an additional line was installed on the rear alley of the barn.

Sprinkler nozzles were spaced 156 inches apart on center and the total application rate was 35 gallons per cycle. The system was activated as described above.

Fans for all treatments were activated both day and night when the temperature rose above 70° F. When wind speed was less than 15 mph, fans in all barns were manually switched off.

Milk production and days in milk did not differ among treatments at the beginning of the study (Table 5). Average milk production and intake was similar during the trial. Heifers (Table 6) had lower milk production at the start and during the trial than older cows, but neither heifers nor cows differed in treatment response.

Two-row Freestall Barn Supplemental Cooling Recommendations

Based on the data presented, an effective cooling system for a two-row freestall barn would include fans over the freestalls and a sprinkler line over the cow feedline. Installing additional fans or sprinkler area did not increase milk production in this study. Fan spacing should be similar to that of the four-row recommendation. The use of an additional sprinkler line on the rear alley did not enhance milk production. Therefore, use of sprinklers on the feedline only is recommended.

Summary

Effective freestall barn cooling is comprised of three steps. First, enhance natural ventilation through a building design, which allows for maximum natural ventilation and protection from solar radiation. Considerations include barn orientation, sidewall height and clear opening, roof slope, ridge opening, building width and wind protection. Failure to follow design criteria will reduce natural ventilation. Removing natural and artificial barriers to wind increases building ventilation rates.

Second, provide adequate water space and volume. Water consumption increases as temperatures increase. So it is critical to have enough water available for all cows. Consider water space per cow, water location, crossover width, and a correctly designed water delivery system.

Third, use effective supplemental cooling systems that are cost effective. Using feedline sprinklers that wet the cow and then allow water to evaporate are effective in reducing heat stress. By wetting the cow, a major portion of the energy used to evaporate the water is derived from the cow. By using short wetting cycles, wet-dry cycles can be implemented each hour. In addition to feedline sprinklers, use fans to increase air circulation. This not only provides cooling but more importantly, increases evaporation rates by moving drier, less humid air over the body surface of the cow.

Heat-stress reduction can be effective and profitable. Systems should enhance natural air exchange in the freestall building and increase body surface cooling of the cow.

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Kansas State University Agricultural Experiment Station and Cooperative Extension Service

EP 76 February 2001

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