ODV MEETING
2012

DAIRY FACILITIES BOTTLENECKS, BENEFITS, AND BEYOND

Heat Stress Abatement in Naturally Ventilated 4-Row Freestall Barns (Head to Head Stalls) Using TeeJet® Turbo Jet Nozzles

J.P. Harner[1], J.F. Smith[1], G. Boomer[2] and M. Brouk[1]

Facts on Heat Generation

- Cows produce about 4,500-6,000 BTU's per hour depending on the level of milk production
- A cow's heat production is similar to a 1,500 W hair dryer during a one-hour period
- The heat produced by a cow in one day is equivalent to the heat produced when 1.2 gallons of propane is burned

Management strategies to reduce heat stress in freestalls

- Open sidewalls and ridge row to maximize natural ventilation.
- Use a soaker over the feed line.
- Increase soaking frequency with temperature.
- Adding fans has little benefit unless a good soaker system is installed first.
- Place single row of fans over feed line and freestalls with head to head stall arrangements (Figure 1).
- Maintain a minimum of 150 ft open space between buildings with 4-row freestalls.

Enhancing Natural Ventilation

- 14 sidewalls (measured above concrete stem wall or curb) with at least 80 percent opening
- 4/12 roof slope
- Ridge row should be open a minimum of 2 inches per 10 feet of building width

Fans Specifications

- Post Spacing 24 ft to 30 ft: One 36-inch fan per post spacing
- Post Spacing less than 20 ft: One 48-inch fan every other post
- Ideal distance between rows-20-24 feet for 36-inch fans and 30-36 feet for 48-inch fans
- Fan Location: (See Figure 1)
  - Head to head freestalls: one row of fans
  - Feed Line – one row of fans
- Mounting Height – bottom of the fan as low as possible allowing adequate head space to operate equipment (7 to 8 feet from the ground to the bottom of the fan is ideal)
- Mount fans such that air flow is with prevailing winds
- Thermostat turns fans on when barn temperature reaches 70ºF

Soaker System

- Approximate system capacity = .33 gallons per cow per cycle
- Thermostat turns soakers on when pen temperature reaches 70ºF
- Soaking Frequency
  - 70-80 ^{o}F Every 15 minutes
  - 81-90 ^{o}F Every 10 minutes
  - > 90 ^{o}F Every 5 minutes

- On time per cycle will depend on the nozzle size and will generally be 1 to 2 minutes
- Mounting height – 6 to 12 inches above top of the headlocks or 5-6 ft above floor
- Pressure in distribution line should be 15 to 20 psi.
- Spacing between nozzles, 6-8 feet
- The size of the water source line and the distribution line will be dependent on the nozzle size, spacing between nozzles and the length of the distribution line (Table 1 and 2).

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[1] Animal Sciences and Industry, Kansas State University, Manhattan, Kansas
[2] Monsanto Dairy Business, St. Louis, Missouri

- Different examples of plumbing the distribution lines are in Figures 3,4 and 5.
- Pictures of plastic and brass TeeJet® nozzles can be viewed in Figure 6.
- Nozzles need to have check valves to prevent the distribution line from draining after each cycle.

Utilities Required

- Electrical service for additional fans – ¾ kVA per fan horsepower
- Water supply – 1 gallon per 10 cows per cooling cycle

List of Suppliers

Nozzles

http://www.teejet.com/products/nozzles.htm

Plastic TeeJet® Adapter and Cap (Nozzle)

QJ8360-NYB – Quick TeeJet system (Adapter)

25600–4–NYR – Quick TeeJet cap for above adapter

Brass TeeJet® Parts (Nozzle)

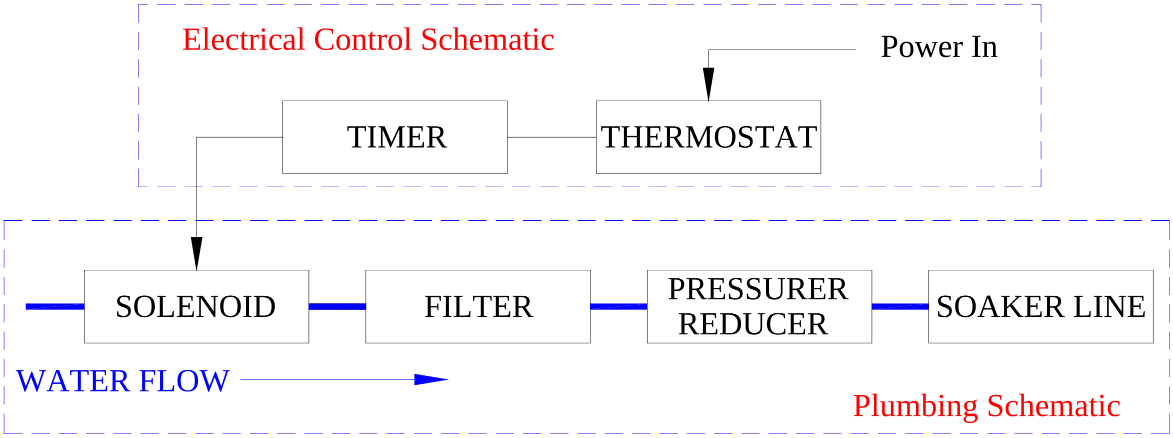
CP1322- Body
CP1325 - Cap
4193A-10-24SS - Check Valve

Plastic TeeJet® Tips for both the plastic and brass nozzles (Turbo FlodJet Tips)

TF-VP-5 (.6 gal/min at 15 PSI)
TF-VP-7.5 (.85 gal/min at 15 PSI)

Controllers
http://www.agselect.com/ED/showprod.cfm?&DID=11&CATID=2&ObjectGroup_ID=4
http://www.meter-man.com/agprods.html
http://www.farmtek.com/

Schematic of Electrical Control and Plumbing



References

Brouk, M.J., J.F. Smith, and J.P. Harner, III. 2003. Effect of sprinkling frequency and airflow on respiration rate, body surface temperature and body temperature of heat stressed dairy cattle. *Proc of* Fifth International Dairy Housing Conference, Fort Worth, TX, pp 263-368.

Brouk, M.J., J.F. Smith, J.P. Harner III, and S.E. DeFrain. 2001. Effect of Fan Placement on Milk Production and Dry Matter Intake of Lactating Dairy Cows Housed in a 4-Row Freestall Barn. KSU Dairy Day Report of Progress 881:4-10.

Brouk, M.J., J.F. Smith, J.P. Harner III, B.J. Pulkrabek, D.T. McCarty, and J.E. Shirley. 1999. Performance of Lactating Dairy Cattle Housed in a Four-Row Freestall Building Equipped with Three Different Cooling Systems. KSU Dairy Day, Report of Progress 842:23-27.

Table 1. Recommended pipe diameter for different nozzle capacities based on feed line length. The nozzle capacity influences the time required to apply 0.05 inches of water per on-cycle.

	NOZZLE CAPACITY (gallons per minute)						
Pipe Diameter (inches)	**0.5 gpm**		**0.75 gpm**		**1.0 gpm**		**Inlet Water Demand (gpm)****
	Feedline Length (feet)	Number of Nozzles*	Feedline Length (feet)	Number of Nozzles*	Feedline Length (feet)	Number of Nozzles*	
1.00	200	25	140	18	100	12	12
1.25	320	40	210	25	160	20	20
1.50	480	60	320	40	240	30	30
2.0	800	100	530	70	400	50	50
2.5	1600	200	1000	125	800	100	100
On Cycle for 0.05 in	2.5 minutes (150 seconds)		1.7 minutes (100 seconds)		1.25 minutes (80 seconds)		

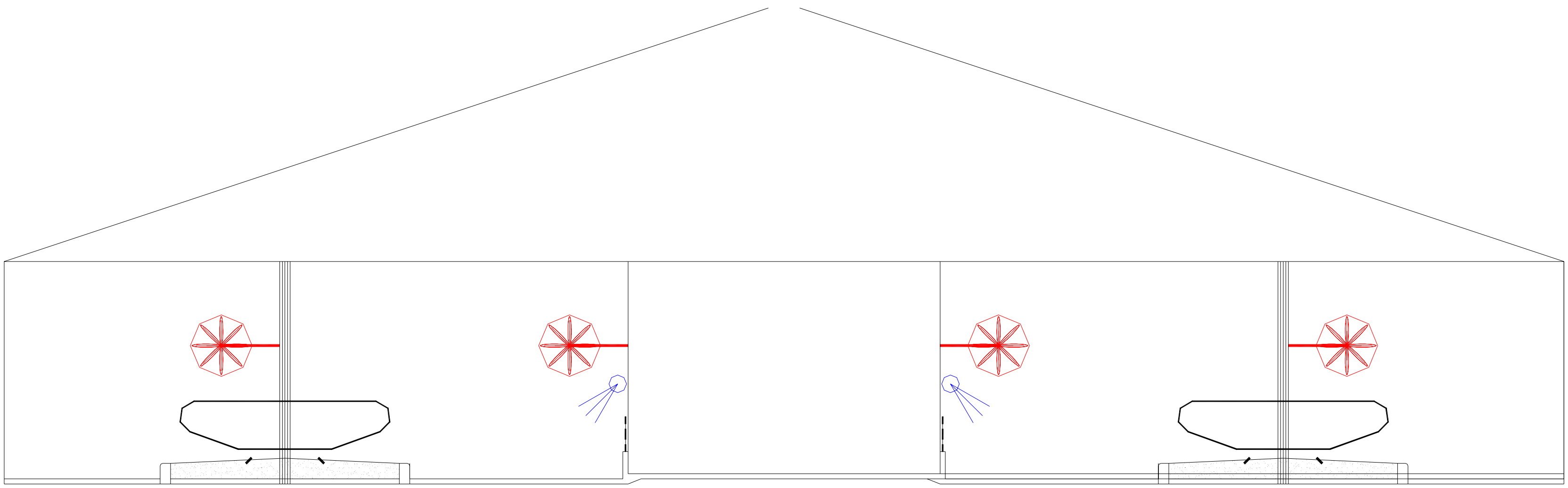
* Assume nozzle spacing is 8 feet on center using the agricultural spray nozzles with a minimum of 20 psi pressure at the outlet of the nozzle.
** Water demand based on a maximum of 5 feet per second flow velocity in the pipe.

Table 2. Impact of spacing between nozzles on inlet water demand (gallons).*

	Spacing Between Nozzles			
Feedline Length (feet)	**8 feet**	**7 feet**	**6 feet**	**5 feet**
100	12	14	17	20
160	20	23	27	32
240	30	34	40	48
400	50	57	67	80
800	100	114	113	160

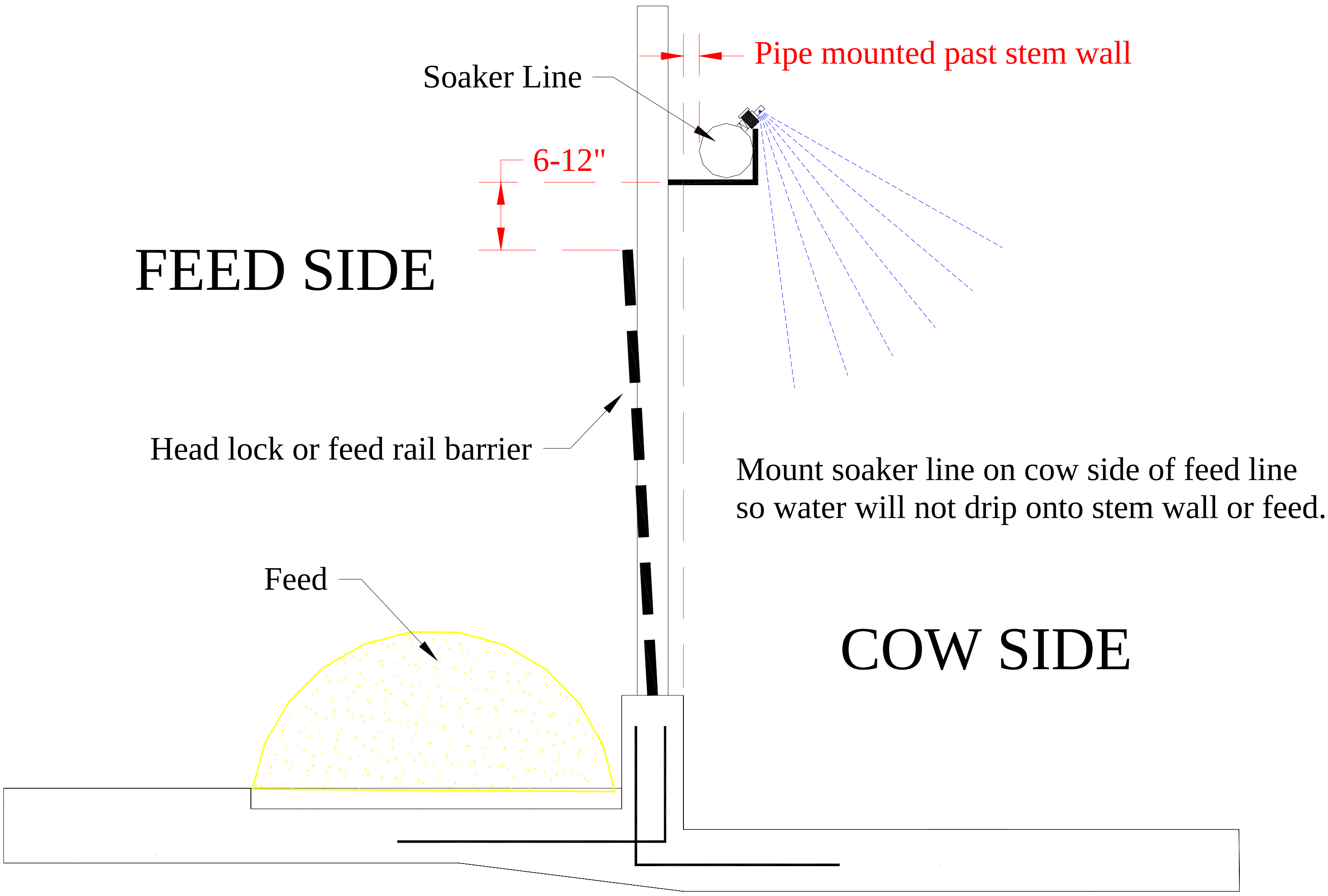
*Calculated using a nozzle that will deliver 1 gallon of water per minute.

Figure 1. Recommended fan placement in a 4-row freestall barn with head-to-head stalls.



Repeated field trials at Kansas State University have shown that optimum performance was obtained by placing a single row of fans over the feed line and the freestalls arranged in a head to head configuration. Milk production is increased 5-6 pounds per cow per day when fans are located on both the feedline and the freestalls versus only locating fans on the feedline or over the stalls.

Figure 2. Soaker line location on the feedline.



Adequately sized supply and distribution lines are essential in the design of a soaker system. Enough water must be supplied in a 1 to 2 minute interval to wet cows along the entire feed line. If either pipe is undersized, nozzles at one end of the feed line may not be on as long as those near the main water line. This causes cows to bunch towards the end where adequate water is supplied. Shown below are three diagrams of the same barn but with the main supply line connecting to the soaker line (distribution line) at different locations (8 feet between nozzles and .75 gallons per minute per nozzle).

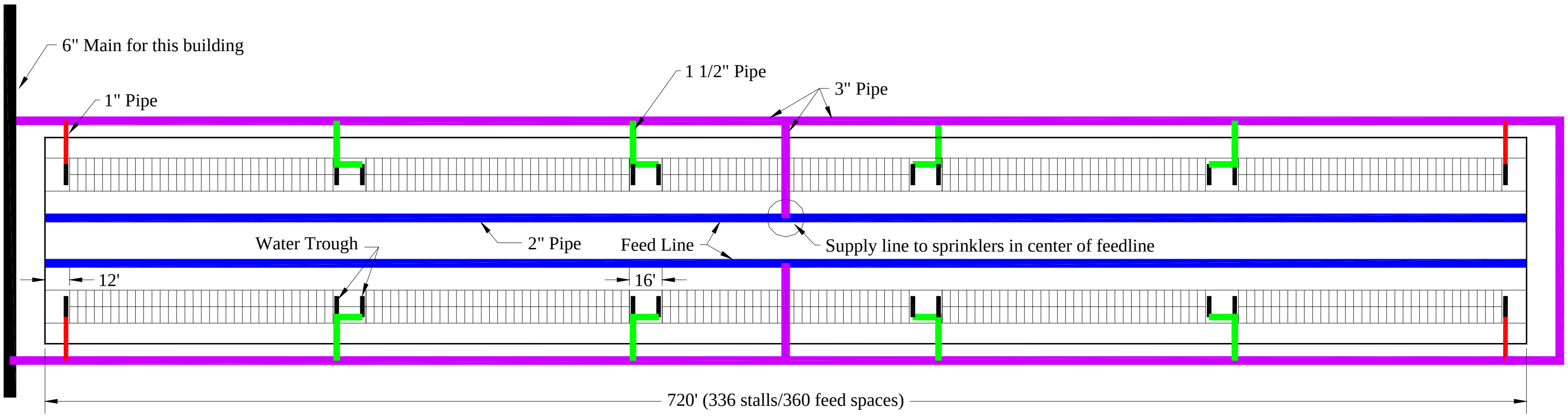


Figure 3. Diagram showing recommended pipe sizes for a soaker system that has the main supply line in the center of the feed line.

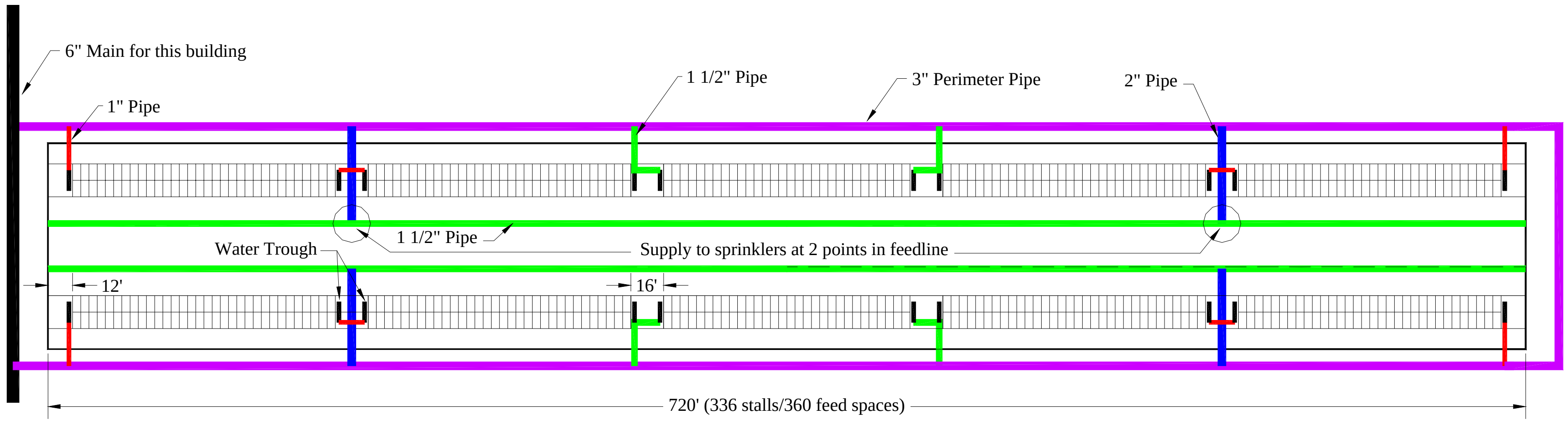


Figure 4. Diagram showing recommended pipe sizes for a soaker system that has the main supply line at two locations along the feed line.

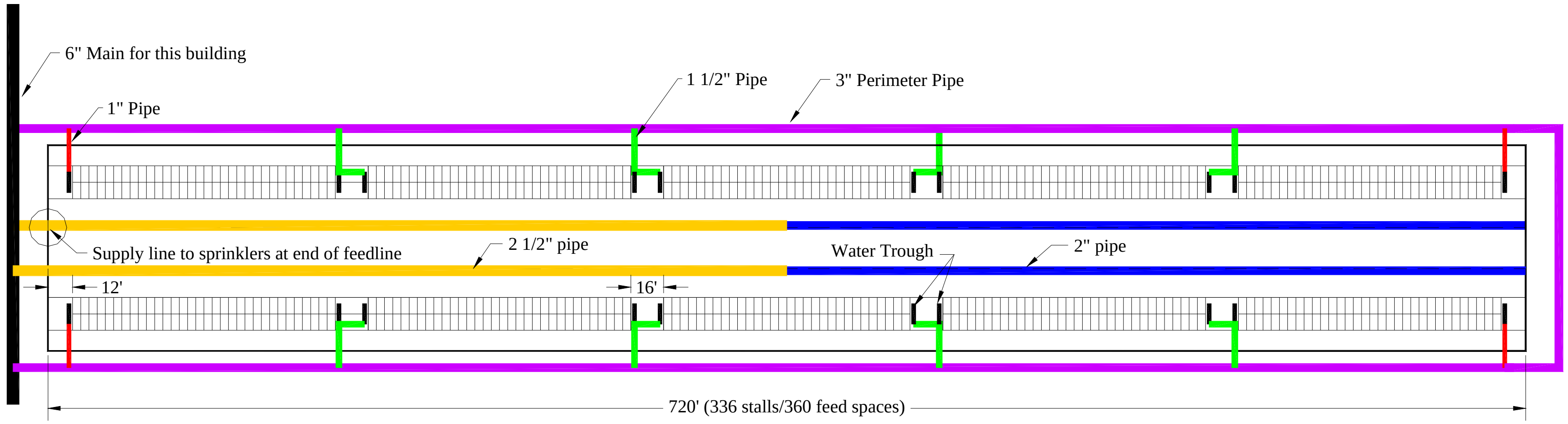


Figure 5. Diagram showing recommended pipe sizes for a soaker system that has the main supply line at one end of the feed line.

Figure 6. Examples of the brass and plastic TeeJet® nozzles.

Heat Stress Abatement in Holding Pens with Nelson and Senninger Nozzles

J.P. Harner[1], J.F. Smith[1], G. Boomer[2] and M. Brouk[1]

Research Studies on Heat Stress in Holding Pen

- Study 1: Body temperature decreased 3.5ºF and milk production increased 1.7 pounds per cow per day when cows were cooled
- Study 2: Milk production increased 5 lbs per day when cows were cooled for 30 minutes five times per day in the holding pen

Facts on Heat Generation

- Cows produce about 4,500-6,000 BTU's per hour depending on the level of milk production
- A cow's heat production is similar to a 1,500 W hair dryer during a one-hour period
- The heat produced by a cow in one day is equivalent to the heat produced when 1.2 gallons of propane is burned

Management strategies to reduce heat stress in holding pen

- Reduce group size to minimize time in holding pen
- Alter milking times if the parlor is not used at full capacity or milk low producing and heifers during hottest part of the day
- Open up the sidewalls and ridge vents to enhance natural ventilation
- Install fans to mechanically ventilate the holding pen during hot weather
- Install a soaker system to increase the evaporative cooling from cows

Enhancing Natural Ventilation

- Sidewalls with at least 60 percent opening
- Remove ridge caps or open up ridge vents
- Ridging opens a minimum of 2 inches per 10 foot of pen width

Fans Specifications

- Option 1: One 36-inch fan per 10 cows or 150 square feet in the holding pen
- Option 2: One 48-inch fan per 20 cows or 300 square feet in holding pen
- Ideal distance between rows-20-24 feet for 36-inch fans and 30-36 feet for 48-inch fans
- Maximum distance between rows – 30 feet for 36-inch fans and 40 feet for 48-inch fans
- Mounting Height – bottom of the fan as low as possible allowing adequate head space to operate equipment
- Mount fans such that air flow is away from milk parlor
- Thermostat turns fans on when holding pen temperature reaches 72ºF

Soaker System

- Approximate system capacity = 1 gallons per 150 square foot of pen space
- On-off cycle – 1 minute on and 5 minutes off
- Thermostat turns soakers on when holding pen temperature reaches 72ºF
- Mounting height – at least 8 feet above the floor
- Pressure in distribution line should be 15 to 20 psi.

Utilities Required

- Electrical service for additional fans – ¾ kVA per fan horsepower
- Water supply – 1 gallon per 10 cows per cooling cycle

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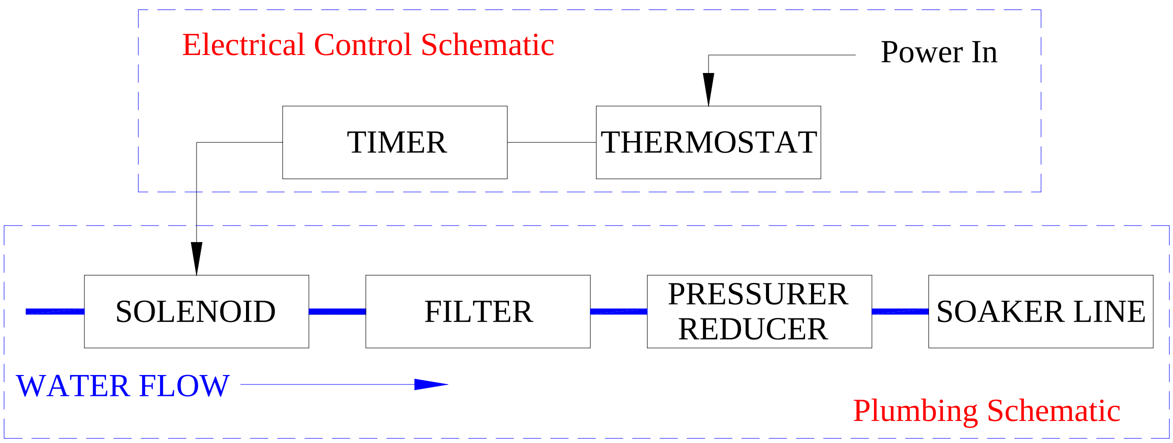
[1] Animal Sciences and Industry, Kansas State University, Manhattan, Kansas
[2] Monsanto Dairy Business, St. Louis, Missouri

List of Suppliers
Nozzles
http://www.nelsonirrigation.com/apps/solidset.cfm
http://www.nelsonirrigation.com/products/index.cfm?id=12&specificproductquery=34
http://www.nelsonirrigation.com/data/products/nozzlesheet.pdf
http://www.nelsonirrigation.com/data/products/D3000.pdf
http://www.senninger.com/
http://www.senninger.com/pages/pv-ldn.html

Controllers
http://www.agselect.com/ED/showprod.cfm?&DID=11&CATID=2&ObjectGroup_ID=4
http://www.meter-man.com/agprods.html
http://www.farmtek.com/

Schematic of Electrical Control and Plumbing



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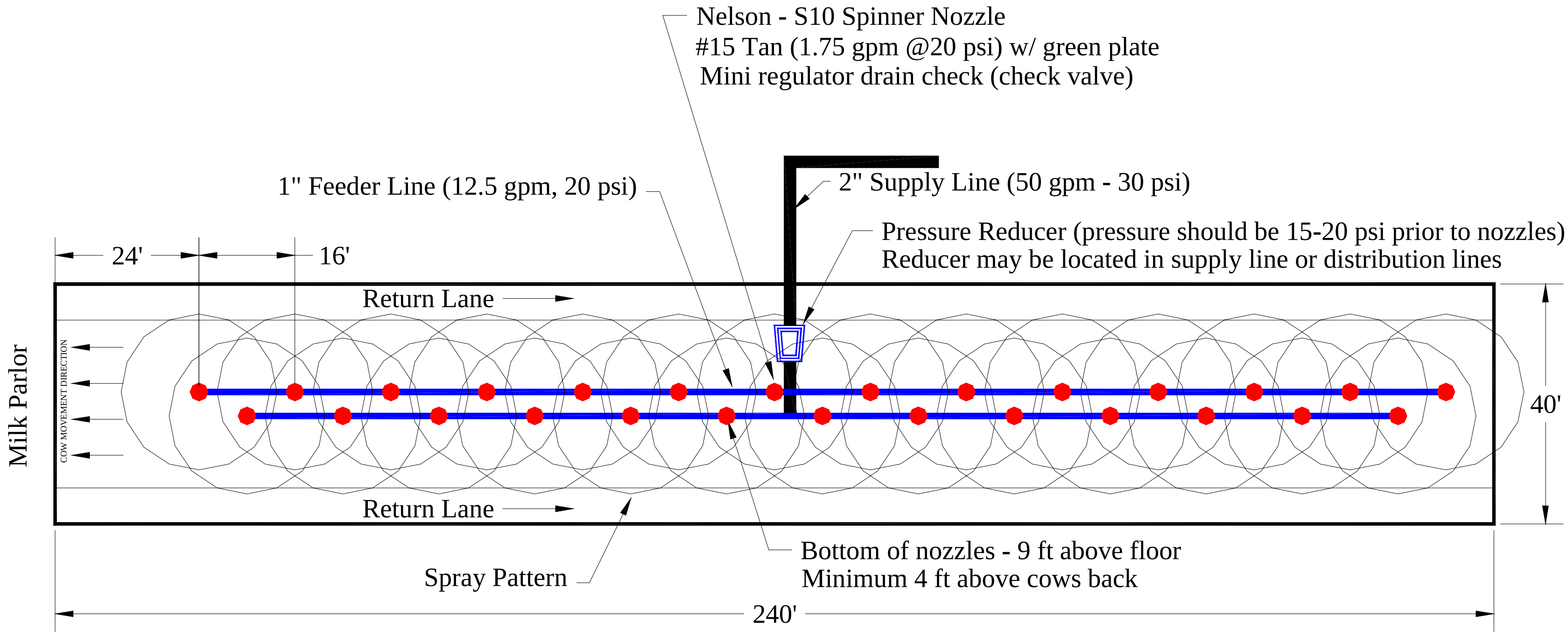
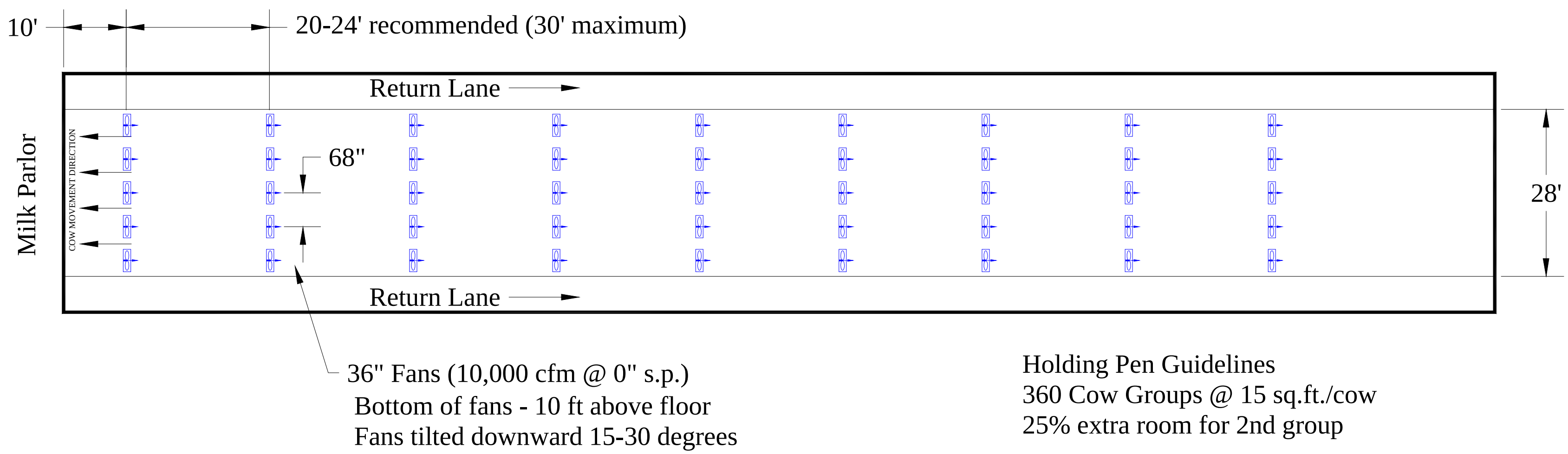
Harner, J.P., J.F. Smith , M.J. Brouk and J.P. Murphy. 2000. Reducing heat stress in the holding pen.. Cooperative Extension Service. Kansas State University. Manhattan, KS.

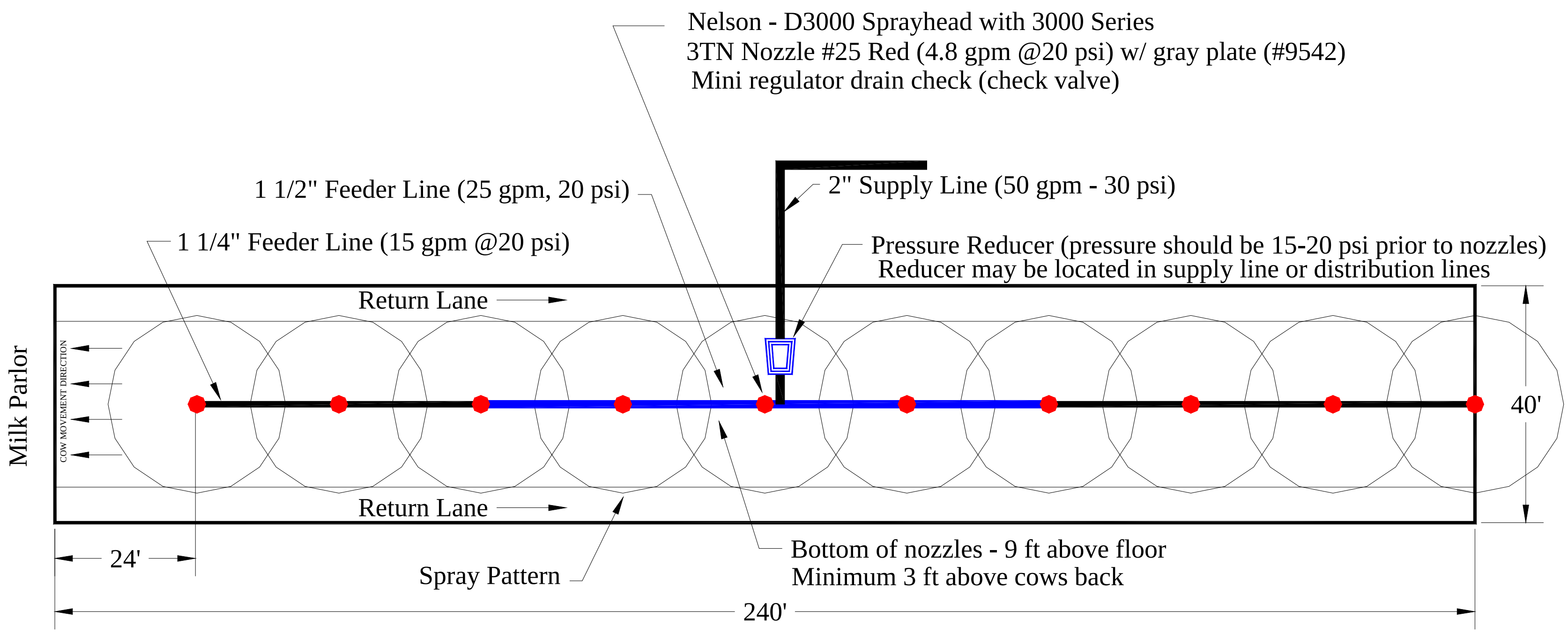
Flamenbaum, I. Et. Al. 1986. Cooling dairy cattle by a combination of sprinkling and forced ventilation and its implementation in the shelter system. J Dairy Sci. 69:3140-3147.

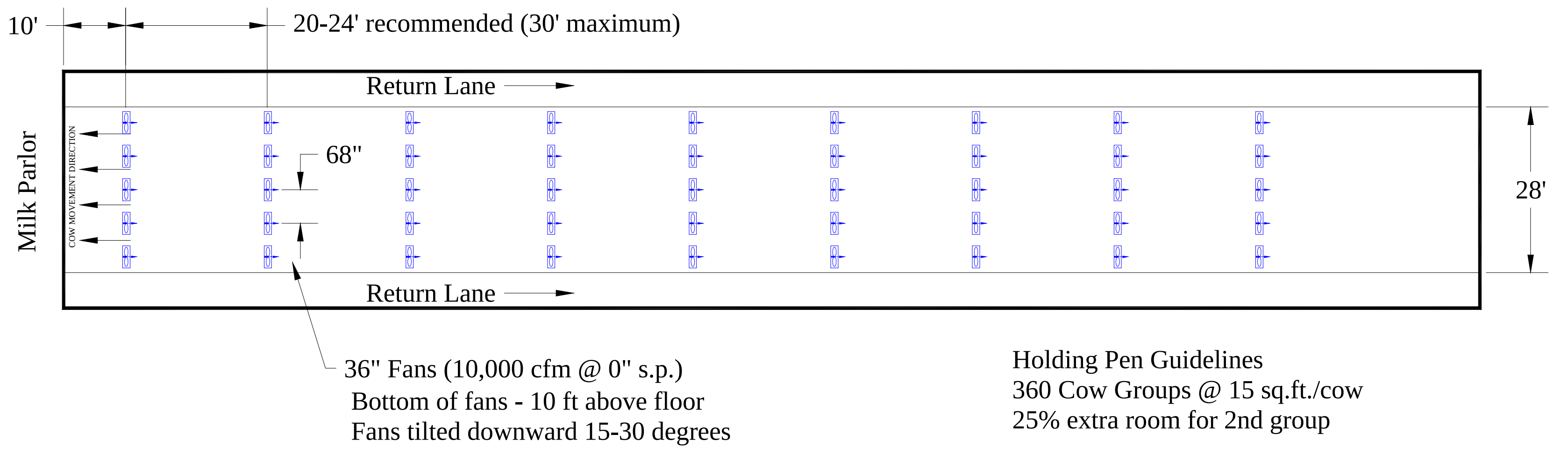
Wiersma, F. and D.V. Armstrong. 1983. Cooling dairy cattle in the holding pen. ASAE Paper No. 83-4507, St. Joseph, MI.





Holding Pen Guidelines
360 Cow Groups @ 15 sq.ft./cow
25% extra room for 2nd group





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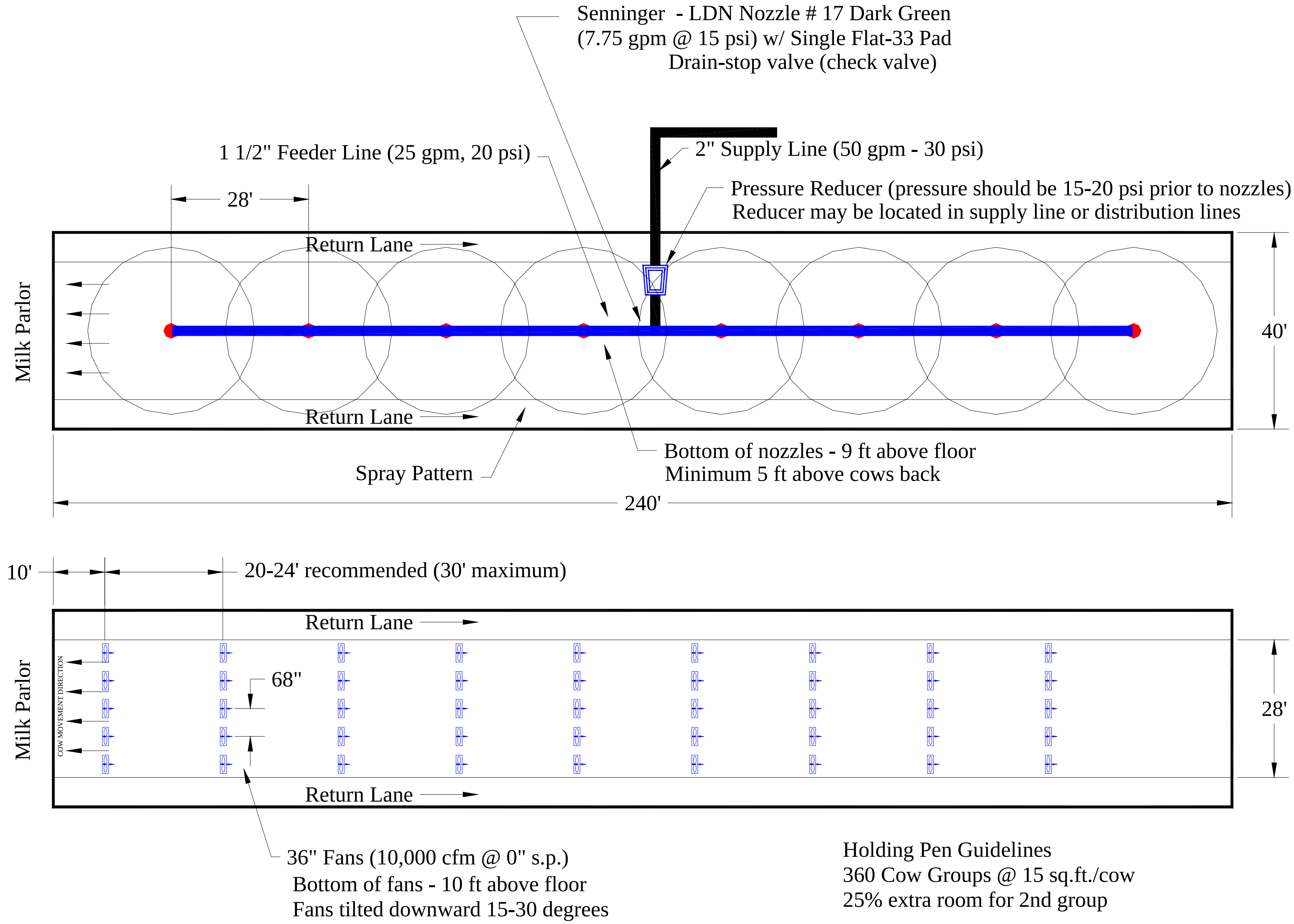

Senninger - LDN Nozzle # 17 Dark Green
(7.75 gpm @ 15 psi) w/ Single Flat-33 Pad
Drain-stop valve (check valve)
1 1/2" Feeder Line (25 gpm, 20 psi)
2" Supply Line (50 gpm - 30 psi)
Pressure Reducer (pressure should be 15-20 psi prior to nozzles)
Reducer may be located in supply line or distribution lines
28'
Return Lane
Milk Parlor
40'
Return Lane
Bottom of nozzles - 9 ft above floor
Minimum 5 ft above cows back
Spray Pattern
240'
10'
20-24' recommended (30' maximum)
Return Lane
Milk Parlor
COW MOVEMENT DIRECTION
68"
28'
Return Lane
36" Fans (10,000 cfm @ 0" s.p.)
Bottom of fans - 10 ft above floor
Fans tilted downward 15-30 degrees
Holding Pen Guidelines
360 Cow Groups @ 15 sq.ft./cow
25% extra room for 2nd group

Dairy Facilities-Putting the Pieces Together

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Introduction

Dairy facilities can have a dramatic impact on the performance and health of dairy cows. Over the years field observations and results from research trials have been used to improve dairy facilities. In the United States producers try to minimize facility cost while trying to maximize milk production per cow, reproductive efficiency, and cow health. Producers often use employees to operate their milking parlors as many hours as possible reducing their fixed cost per cow. Under these conditions producers have to be extremely careful where they invest dollars into dairy facilities. These proceedings will discuss some of the issues faced by dairy producers.

Milking Parlors, Holding Pens and Exit Lanes

Reducing stress on cows in the milking facility is very important. These facilities should be constructed to minimize the time cows are away from feed and water. Ideally lactating dairy cows would be in the housing area a minimum of 20 hours per day. Currently, parallel, and rotary parlors are the two predominant types of parlors constructed. Expanding rotary parlors is difficult. The operator pit can be constructed in parallel and herringbone parlors to allow additional stalls to be added as the dairy expands.

Typically, milking parlors are sized so that cows can be milked once in 10 hours when milking 2x per day; 6.5 hours when milking 3x per day; and 5 hours when milking 4x per day. Using these criteria, the milking parlor will be sized to accommodate the cleaning and maintenance of the parlor. The facilities or cow groups are determined based on milking one group in 60 minutes when milking 2x, 40 minutes when milking 3x, and 30 minutes when milking 4x. Sizing groups of cows to be milked in these time frames will minimize the time cows are away from feed and water.

The holding pen is the most challenging environment that a dairy cow faces. Holding pen cooling should be used to minimize heat stress in this area. Holding pens are designed based on 1.39-1.49 m^2 (15-16 ft^2) per cow with a group size not greater than 200 cows. If the group size is greater than 200 cows the area per cow should be increased to 1.49-1.58 m^2 (16-17 ft^2) per cow. Ideally the holding pen should be sized to hold 1.25 groups of cows. Over sizing the holding pen by 25 percent allows a second group to be moved into the holding pen while the crowd gate is pulled forward and the first group is finishing being milked (Smith et al., 1997).

Exit lane width is dependent on the number of stalls on one side of the milking parlor. In parlors with 15 stalls or less per side, a clear width of 3 ft is acceptable. For parlors containing more than 15 stalls per side, a clear exit lane width of 5 to 6 ft. is desired (Smith et al., 1997).

The width of cow traffic lanes should be sized according to group size. When group size is less than 150 cows, 14 ft. traffic lanes are typically used. Lane width is increased to 16 ft. for group sizes from 150 to 250 cows, 20 ft. for group sizes from 251 to 400 and to 24 ft. when group size is greater than 400 cows (Armstrong 2001).

Selecting Cow Housing

The predominant types of cow housing in the Western United States are dry-lots and freestalls. This decision is based on climate, management style, and equity available for constructing dairy facilities. In the Midwest United States freestall housing is usually selected to minimize the effect of weather changes, to improve cleanliness, and cow comfort. Providing a clean dry bed is essential to minimize the incidence of mastitis in the herd. The disadvantage of freestall housing is the cost of constructing freestall housing and the costs associated with maintaining the beds and manure management.

One of the critical decisions that producers make is the type of freestall barn they build. The most common types are 4-row or 6-row barns and many times the cost per stall is used to determine which barn should be built. Data found in Table 1 represents the typical dimensions of the barns and Table 2 demonstrates the effects of overcrowding upon per cow space for feed and water. Grant (1998) suggested that feed bunk space of less than 20 cm/cow (8 in/cow) reduced intake and bunk space of 20-51 cm/cow (8-20 in/cow) resulted in mixed results. Even at a 100% stocking rate, the 6-row barn only offers 46 cm/cow (18 in/cow) feed line space. When over crowding occurs this is significantly reduced. Four-row barns, even when stocked at 140% of the stalls, still provide more than 46 cm/cow (18 in/cow) of bunk space. In addition, when water is only provided at the crossovers, water space per cow is reduced by 40% in the 6-row barn as compared to 4-row barns. Research reported by Smith et al., 2001 would indicate that summer respiration rates are higher in 6-row vs. 4-row freestall barns. Many times headlocks are used the primary method used to restrain cows for breeding, estrus synchronization, vaccinations and other common procedures. If headlocks are to be used efficiently there needs to be adequate bunk space to lock up all the cows at the same time. Feedline space recommendations for different groups of cows are presented in Table 3.

Recommendations concerning access to water vary greatly. Current recommendations suggest a range of 3 – 9 linear cm (1.2 to 3.6 linear in) per cow (Smith et al., 2000). In the Midwest, the typical rule is one waterer or 61 cm (2 linear ft) of space for every 10 to 20 cows. In the Southwest, the recommendation is 9 linear cm (3.6 linear in) of space for every cow in the pen. Typically, water is provided at each crossover in 4- and 6-row freestall barns and generally a 4- and 6-row freestall have the same number of crossovers. Thus, water access in a 6-row barn is reduced by 37.5% as compared to a 4-row barn (Table 1). When overcrowding is considered (Table 2) water access is greatly reduced and the magnitude of reduction is greater in 6-row barns. Milk is 87% water and water intake is critical for peak dry matter intake. When building 6-row barns or overcrowding either 4-row or 6-row barns it is important to consider the amount of water space available. In warmer climates, (9 linear cm) 3.6 linear in. of waterer space per cow should be provided.

If construction costs are going to drive the decision between 4- or 6-row freestall barns, overcrowding must be considered. Typically, 4-row barns are overcrowded 10 to 15% on the basis of the number of freestalls in the pen. Due to the limitations of bunk space, many times the 6-row barn is stocked at 100% of the number of freestalls. Thus, comparing the two buildings on a cost per cow basis, rather than a per stall basis would be more accurate. This will make the 4-row more cost comparable to the 6-row and maintain greater access to feed and water.

Table 1. Average pen dimensions, stalls, cows and allotted space per animal.

							------------ Per Cow -----------					
Barn Style	Pen Width		Pen Length		Stall Per Pen	Cows Per Pen	Area		Feedline Space		Water Space	
	m	ft	m	ft			m^2	ft^2	cm	inch	cm	inch
4-Row	11.9	39	73.2	240	100	100	8.7	94	73.7	29	9.1	3.6
6-Row	14.3	47	73.2	240	160	160	6.6	71	45.7	18	5.7	2.25
2-Row	11.9	39	73.2	240	100	100	8.7	94	73.7	29	9.1	3.6
3-Row	14.3	47	73.2	240	160	160	6.6	71	45.7	18	2.25	2.25

Adapted from Smith, J.F. et al., 1999.

Table 2. Effect of stocking rate on space per cow for area, feed and water in 4 and 6-row barns.

Stocking Rate (%)	Area/Cow				Feedline Space/Cow				Water Space/Cow			
	4-Row		6-Row		4-Row		6-Row		4-Row		6-Row	
	m^2	ft^2	m^2	ft^2	cm	inch	cm	inch	cm	inch	cm	inch
100	8.7	94	6.6	71	73.7	29	45.7	18	9.1	3.6	5.7	2.25
110	7.9	85.5	6.0	64.5	66.0	26	40.6	16	5.8	3.27	5.2	2.05
120	7.3	78.3	5.5	59.2	61.0	24	38.1	15	7.6	3.0	4.8	1.88
130	6.7	72.3	5.1	54.6	55.9	22	35.6	14	7.0	2.77	4.4	1.73
140	6.2	67.1	4.7	50.7	53.3	21	33.3	13	6.5	2.57	4.2	1.66

Table 3. Recommended Groups and Facilities for Cows Housed in the Special Needs Area.

Group	Avg. Time in Facility	% of Lactating Herd	Housing System
Close-up cows	21 days	6%	Freestalls or loose housing
Close-up heifers	21 days	3%	Freestalls or loose housing
Maternity cows	3 days	.33%	Loose housing
Maternity heifers	3 days	.33%	Loose housing
Maternity overflow	3 days	.33%	Loose housing
Fresh cows & heifers, Non-sellable milk	2 days	1%	Freestalls or loose housing
Fresh cows	14 days	3.5%	Freestalls
Fresh heifers	14 days	1.5%	Freestalls
Mastitis & sick cows, non-sellable milk	N/A	2%	Freestalls or loose housing
High risk sellable milk	N/A	2 – 6%	Freestalls or loose housing
Cull and dry cows	N/A	1.5%	Loose housing
Calf housing	24 hours		Hutches or small pens

Grouping Strategies

The size and number of cow groups on a dairy are critical planning factors. Factors affecting the number and types of groups are largely associated with maximizing cow comfort, feeding strategies, reproduction and increasing labor efficiency. Lactating cows are allotted to one of seven classifications;

1. Healthy lactating heifers
2. Healthy lactating cows
3. Fresh cows and heifers with non-sellable milk
4. Fresh cows with sellable milk
5. Fresh heifers with sellable milk
6. Sick cows with non-sellable milk
7. High risk sellable.

Healthy lactating heifers and cows are typically housed in 8 – 12 groups. The cows in classifications 3-7 are typically housed in the special needs area along with close-up cows and heifers. Table 3 lists suggested pens and pen sizes for different classifications of dairy cattle to be housed in the special needs facility and Table 4 list recommendations for feedline space and stocking density for different groups of cows.

Heifers respond favorably when grouped separately from older cows. Heifers have lower dry matter intakes and greater growth requirements as compared to older cattle. In addition, mixing heifers with older cattle increases social pressure resulting in less than optimal heifer performance.

Close-up dry cows and springing heifers differ in nutritional requirements. Close-up cows will have greater intakes and are much more likely to develop milk fever than heifers. Springing heifers may also benefit from a longer transition period than normally allowed for cows. Thus, heifers and dry cows should be separated.

Close-up cows should be moved into a close up pen 21 days prior to calving. The diet in this pen typically has greater concentrations of protein and energy as compared to the far off dry cow diet. In addition, the diet should be low in calcium and potassium or contain anionic salts with appropriate amounts of calcium and potassium to prevent milk fever. Milk fever is generally not a problem with heifers but heifers may benefit from receiving the typical transition diet for 5 weeks rather than 3 weeks. Thus, feeding a diet with higher levels of protein and energy without anionic salts for 5 weeks prior to freshening would be beneficial for heifers.

If close-up cows and heifers are housed in freestalls, they would be moved into a maternity pen at the time of calving. Close-up cows and heifers in loose housing would be allowed to clave in the close-up pen. Following calving cows and heifers are typically co-mingled until the milk can be sold. Cows and heifers would be segregated when they move out of the fresh non-sellable pen into the fresh pens. Cows and heifers would be housed in the fresh pens for 14 days where rectal temperatures, dry matter intakes and general appearance can be monitored on a daily basis. Other pens for mature cows and heifers in the special needs area would be a sick pen which would be used to house cows which had been treated with antibiotics and a high risk pen for lame cows and slow milkers who still produced a lot of sellable milk, however, needed some extra attention.

It is important to realize that these group sizes in the special needs area have been increased to account for fluctuations in calving and cow and heifer numbers. If these pens are sized for static or average numbers there will be a considerable amount of time where the special needs facilities would be over stocked. Over stocking cows prior to or after calving can have a dramatic impact on milk production and cow health.

Table 4. Recommended Feedline Space and Stocking Density for Different Groups of Cows.

Group	Feedline/Cow	Freestalls (Cows/Stalls)
Close-up or Pre Fresh	76.2 cm (30 in)	100%
Fresh Cows	76.2 cm (30 in)	100%
Mid to low Lactation	61-76.2 cm (24-30 in)	100%-110%
For off Dry	61-73.2 cm (24-30 in)	110%-110%

Freestall Surfaces

Deep bedded sand is the freestall surface of choice in many areas. It provides a comfortable cushion that forms to the body of the animal. In addition, its very low organic matter content reduces mastitis risk. Sand is readily available and economical in many cases. Disadvantages may include the cost of sand and/or the issues with handling sand laden manure and separating the waste stream. In arid climates, manure solids are composted and utilized for bedding. Producers choosing not to deal with sand or composted manure bedding, often choose from a variety of commercial freestall surface materials. Cows need a stall surface that conforms to the contours of the cow. Sand and materials that compress will likely provide greater comfort as demonstrated by cow preference.

Feed Barrier Design

The use of self-locking stanchions as a feed barrier is currently a debated subject in the dairy industry. Shipka and Arave (1995) reported that cows restrained in self-locking stanchions for a four-hour period had similar milk production and dry matter intake as those not restrained. Arave et al. (1996a) observed similar results in another study, however a second study showed similar intake but 6.4 lb/cow/d decrease in milk production when cows were restrained daily for a four hour period (9 AM to 1 PM) during the summer. Increases in cortisol levels were also noted during the summer but not in the spring (Arave et al., 1996b) indicating increased stress during the summer as compared to the spring. Another report (Bolinger et al., 1997) found that locking cattle for 4 hours during the spring months did not affect milk production or feed intake. All of these studies compared restraining cows for four hours to no restraint and all animals were housed in pens equipped with headlocks. The studies did not compare a neck rail barrier to self-locking stanchions nor address the effects of training upon headlock acceptance. The argument could be made that four hours of continuous restraint time is excessive and much shorter times (one hour or less) should be adequate for most procedures. These studies clearly indicate that mismanagement of the self-locking stanchions, not the stanchions resulted in decreased milk production in one of three studies with no affect upon intake in all studies.

Another study (Batchelder, 2000) compared lockups to neck rails in a 4-row barn under normal and crowded (130% of stalls) conditions. Results of the short-term study showed a 3-5% decrease in dry matter intake when headlocks were used. No differences in milk production or body condition score were observed. It was also noted that overcrowding reduced the percentage of cows eating after milking as compared to no overcrowding. In this study, use of headlocks reduced feed intake but did not affect milk production.

A study was conducted by Brouk et al. in the summer of 2000 to determine the effect of headlocks and neckrails on milk production and dry matter intake. This trial was conducted on a commercial dairy and included 216 lactating Holstein cows (55, 2 year olds and 53 mature cows per pen) previously exposed to headlocks. Headlocks did not adversely affect milk production or dry matter intake in this trial. In summary, it does not appear that headlocks adversely affect milk production if they are managed correctly.

The feeding surface should be smooth to prevent damage to the cow's tongue. When eating, the side of the tongue, which is much more easily injured, often contacts the manger surface. The use of plastics, tile, coatings, etc. will provide a smooth durable surface reducing the risk of tongue injury.

Cow Handling Systems

The current cow handling systems are lock-ups, sort gates, palpation rails, chutes, and combinations of the systems listed previously. Sort gates require electronic identification. They work fairly well to sort groups of cows of the parlor to be moved, beefed, dried off, etc. Managing reproduction as cows leave the milking parlor using sort gates is very difficult. Often times cows can not be processed fast enough putting employees and veterinarians in a position where they have to watch the clock. Inevitability, a second holding pen is created increasing the time cows are away from feed and water. This also creates a situation where cows can very easily end up in the wrong pen after they are processed. Headlocks have been used in the western United States for many years. Headlocks are a very efficient way to handle large number of cows, however, they can be mismanaged. Producers should strive to reduce lock-up times to 1 hour per day. Locking cows up in the afternoon during summer months should be avoided. Heifers should be exposed to and trained to use lockups prior to entering the close-up pen.

Managing Heat Stress

Heat stress management is a critical factor that needs to be considered when designing a dairy facility. The factors that need to be considered are discussed in a separate paper in these proceedings.

Facility Bottlenecks to Cow Cooling

Often producers do not plan to cool cows when they are building new dairy facilities. This creates serious problems in cooling cows. The biggest bottleneck is water availability to soak cows on the feedline in cow housing areas. Another problem is the lack of provisions to provide electricity for fans. It is much more economical to put the electrical system necessary for fans when the structures are built versus retrofitting the wiring at a later date. The majority of the dairies being built today do not have water or electrical systems to meet the demands of cow cooling.

Supplemental Lighting

Supplemental lighting has been shown to increase milk production and feed intake in several studies. Peters (1981) reported a 6% increase in milk production and feed intake when cows were exposed to a 16L:8D photoperiod as compared to natural photoperiods during the fall and winter months. Median light intensities were 462 lx and 555 lx for supplemental and natural photoperiods respectively. Chastain et al. (1997) reported a 5% increase in feed intake when proper ventilation and lighting were provided and Miller et al. (1999) reported a 3.5% increase without bST and 8.9% with bST when photoperiod was increased from 9.5-14 h to 18 h. Increasing the photoperiod to 16-18 h increased feed intake. Dahl et al. (1998) reported that 24 h of supplemental lighting did not result in additional milk production over 16 hours of light. Studies utilized different light intensities in different areas of the housing area. More research is needed to determine the correct light intensity to increase intake. In modern freestall barns, the intensity varies greatly based on the location within the pen. Thus additional research is needed to determine the intensity required for different locations within pens.

Another issue with lighting in freestall barns is milking frequency. Herds milked 3x can not provide 8 hours of continuous darkness. This is especially true in large freestall barns housing several milking groups. In these situations, the lights may remain on at all times to provide lighting for moving cattle to and from the milking parlor. The continuous darkness requirement of lactating cows may be 6 hours (Dahl, 2000). Thus, setting milking schedules to accommodate 6 hours of continuous darkness is recommended. The use of low intensity red lights may be necessary in large barns to allow movement of animals without disruption of the dark period of other groups.

Dry cows benefit from a different photoperiod than lactating cows. Recent research (Dahl, 2000) showed dry cows exposed to short days (8L:16D) produced more ($P<.05$) milk in the next lactation than those exposed to long days (16L:8D). Petitclerc et al. (1998) reported a similar observation. Based on the results of these studies, dry cows should be exposed to short days and then exposed to long days post-calving.

Manure Management

Dairies will generate .9-1.4 kg (2-3 lb) of manure and wastewater per kg (lb) of milk produced. Most dairies are using a flush system to transport the manure from the alleys, pens or housing area to the storage area. Experiences in Kansas suggest the flushing wave velocity needs to be 2.3-3.1 meters per second (7.5 - 10 fps) with a 20 sec contact time to adequately flush alleys along side of sand bedded freestalls. Flushing is improved by sloping the buildings 2-3 percent. Freestalls bedded with sand use an average of 22.7 kg (50 lb) of sand per cow per day. Dairies can reclaim sand with gravity or mechanical sand separators. Sand separation generally requires stocking piling reclaimed sand prior to reuse or blending with clean sand.

The manure and effluent are generally stored in a solids storage basin and liquid storage lagoon. These structures have to meet state and/or federal guidelines. The solid storage basin is normally built as economical as possible. However, this may not be the most cost-effective decision. Operations, which have weekly or monthly hauling, will invariably have to keep cropland out of production to have adequate land available for solid manure disposal. Cropping practices should be considered during the design stage. Effluent from lagoons is normally applied to growing crops if possible. This requires having adequate land available to install irrigation equipment for maintaining storage volume. Stock piling manure on berms or at the edge of fields to provide additional storage requires additional handling and containment structures to control nutrients leaching from the stockpile area.

Putting the Pieces Together

Designing and constructing a dairy facility to maximize cow comfort and labor efficiency is a big challenge. Some of the common mistakes include;

1. Group size does not match up with the parlor size. The result is that cows spend too much time away from feed and water.
2. Freestall barns are orientated north south to save on dirt work putting the cows in the sun.
3. The manure system is not designed to handle sand bedding in the freestalls.
4. Close-up and fresh cow housing is undersized.
5. The cow cooling system does not match up with the environment.
6. The cow handling system creates a situation where cows are away from feed and water too long.
7. Insufficient access to water.

Careful planning will help prevent many of these problems into a new facility. It is extremely important to keep the investment per cow as low as possible, while increasing the production per cow.

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Impact of Ohio Weather on Managing Dairy Facilities

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Cold and heat stress influence dairy cow performance. Figure 1 show the percent annual hours within 5 °F degree temperature ranges for Dayton, Ohio. During the energy crisis of the 1970's each military base complied weather data to enable resources to be focused towards appropriate energy conservation practices. The data in Figure 1 was plotted using the 5 years of hourly weather data compiled for the Wright-Patterson Air Force base. The thermal neutral zone of a dairy cows is in the range of 20 to 70 °F. The data shows for Dayton, Ohio annually less than 6 % of hours are below 20 °F. However, cow's experience heat stress when temperatures exceed 70 °F nearly 18 % of the time during a year. Outdoor temperatures are in the thermal neutral zone about 75 % of the time during the year. Therefore, Ohio dairy producers should focus on minimizing heat stress prior to focusing on cold stress.

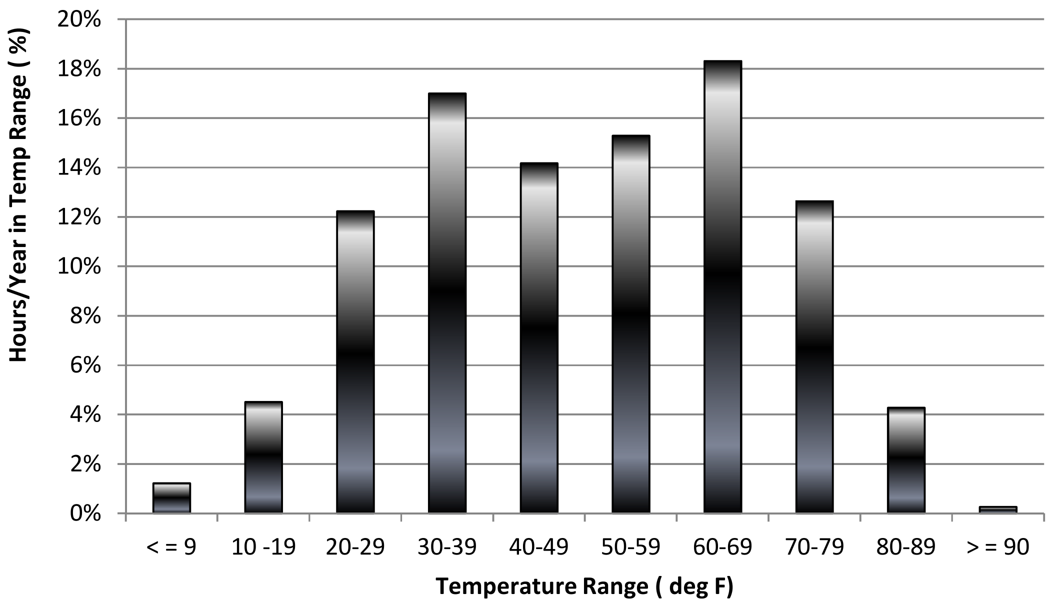

Figure 1 Annual hours (percent) of weather data in 5 °F temperature ranges for Dayton, Ohio

Weather data may be used to estimate water requirements for low pressure sprinkler systems used in heat abatement. The annual hours at Akron between 70 and 79 °F equaled 73.5 %, between 80 and 89 °F equaled 24.9 % and only 1.6 % hours above 90 °F. Temperature controllers allow water to be applied 1 minute on and 14 minutes off (15 minute cycle) between 70 and 79°F, 1 minute on and 9 minute off (10 minute cycle) between 80 and 89 °F and above 90°F, 1 minute on and 4 minute off (5 minute cycle). With a 1 gpm low pressure nozzle and spacing of 8 ft above the feedline, annual water usage for heat abatement would equal approximately 1,750 gallons for cooling cows. Water usage with low pressure systems is not 100 % efficient since the systems operates based on temperature rather than cows present at the feedline. This results in some water entering the storage pond requiring land disposal. Based on $0.02 per gallon of water for disposal, cost estimate for application of the extra water is estimated at $20 per cow per summer. Basically, 1 ½ cwt of extra milk is required to pay for the cost of excess water disposal.

Figure 2 shows weather data from three military bases in Ohio including Dayton, Cincinnati and Akron. The data suggest cows experience temperatures below 20 °F less than 6 percent of the time during a year. Temperatures above 70 °F occur nearly 20 percent of the year in Ohio based on these 3 locations.

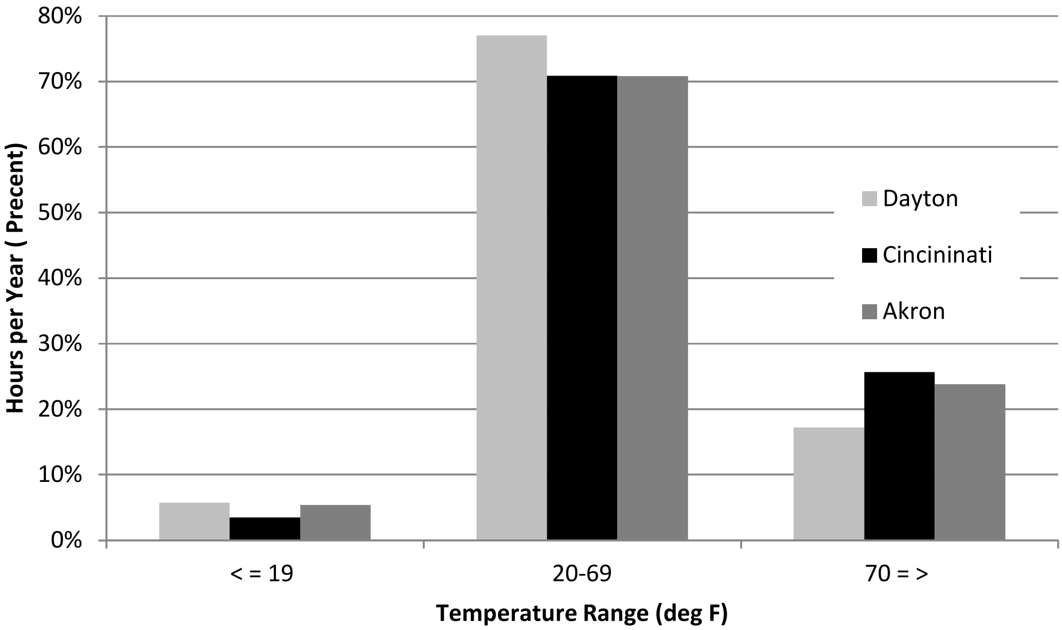

Figure 2 Annual hours (percent) at three locations in Ohio within various temperatures

Figure 3 shows the hourly weather data from August 1-14, 2011 for Columbus, Ohio. The temperature ranged from 58 °F to 91 °F with an average of 77 °F. The relative humidity averaged 70 % (31 to 94 %) and the temperature humidity index averaged 73.5 (58 to 82.2) during this two week period. Nearly 50 percent of the time the temperatures exceed 75 °F.

Figure 4 plots the range of relative humidity and THI values for a given temperature during this period. For example at 75 °F, the relative humidity ranged from 40 to 90 %, while the THI ranged from 70 to 75. The THI value is influenced more by temperature than relative humidity resulting in a close correlation between temperature and THI (R^2 = 0.93) as shown in Figure 4. However, the correlation between temperature and relative humidity is poor (R^2= 0.42). Evaporative cooling is more effective at lower relative humidity. The variability of the relationship between temperature and relative humidity as shown in Figure 4 indicates there will be periods when cows may still experience some heat stress in spite of low pressure systems or evaporative cooling systems. In dairy regions where there is poor correlation between temperature and relative humidity, the recommendations is to install a low pressure sprinkler systems over the feedline even if there is an evaporative cooling systems is the primary cooling system. This is based on the assumption there is adequate airflow in the stall or resting area. At higher humidity, low pressure systems will be more effective.

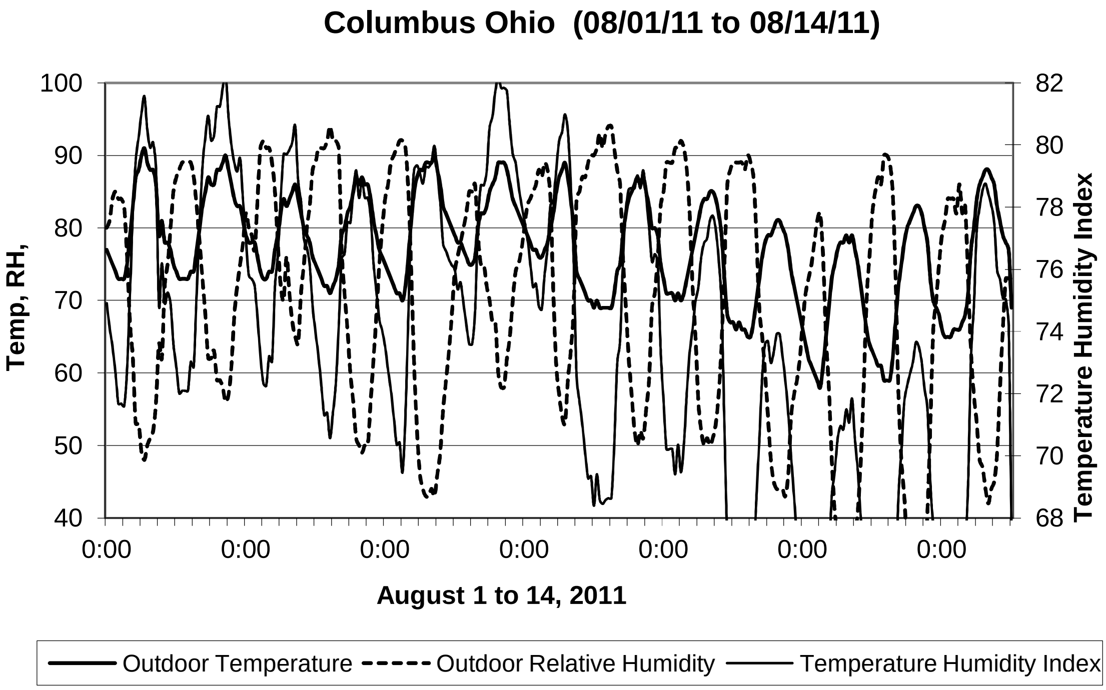

Figure 3 Hourly temperature, relative humidity and temperature humidity index between August 1-14, 2011 for Columbus, Ohio

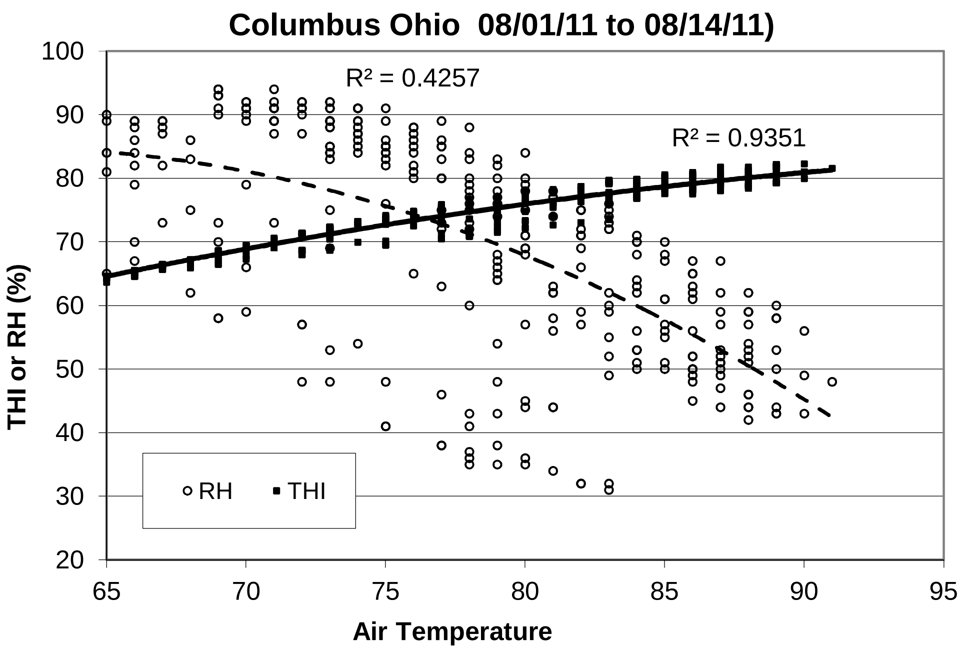

Figure 4 Range of relative humidity and temperature humidity indices for a given temperature between August 1-14, 2011 for Columbus, Ohio

Weather data may be used to evaluate the effectiveness of evaporative cooling systems. Figure 5 compares the ambient THI index to the THI index assuming an evaporative cooling system was 100 percent efficient during the August 1 to 14, 2011 in Columbia, OH. The poor correlation between the temperature and 100 percent efficient values is a due to the variability of relative humidity (Figure 3 or 4). However, the plot indicates the potential to lower the THI values via evaporative cooling. The THI indices may be reduced to less than 75 even when temperatures are above 85 °F using an evaporative cooling system. In spite of the variability of the relative humidity, evaporative cooling has the potential to have significant effect on reducing heat stress or lower the THI value.

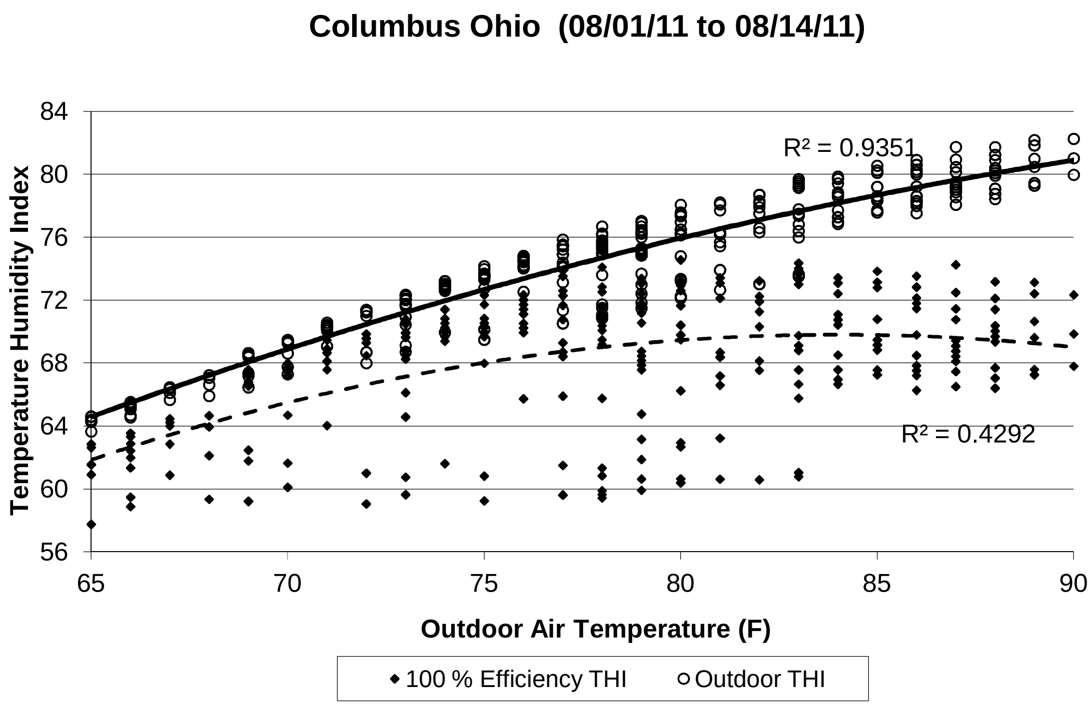

Figure 5 Impact of evaporative cooling on the THI assuming 100 percent efficiency during August 1-14, 2011 in Columbus, Ohio

Figure 6 plots the temperature drop assuming the evaporative cooling system is 100 percent efficient during August 1-14, 2011 in Columbus, Ohio. For given temperature such as 75 °F, temperature drops of 2 to 16 °F are possible depending on the relative humidity. As previously noted, the variability in relative humidity influences the potential temperature drop. For a given temperature, the temperature drop will be greater as the relative humidity decreases. The average temperature drop is 6 °F at 75 °F outdoor air temperatures.

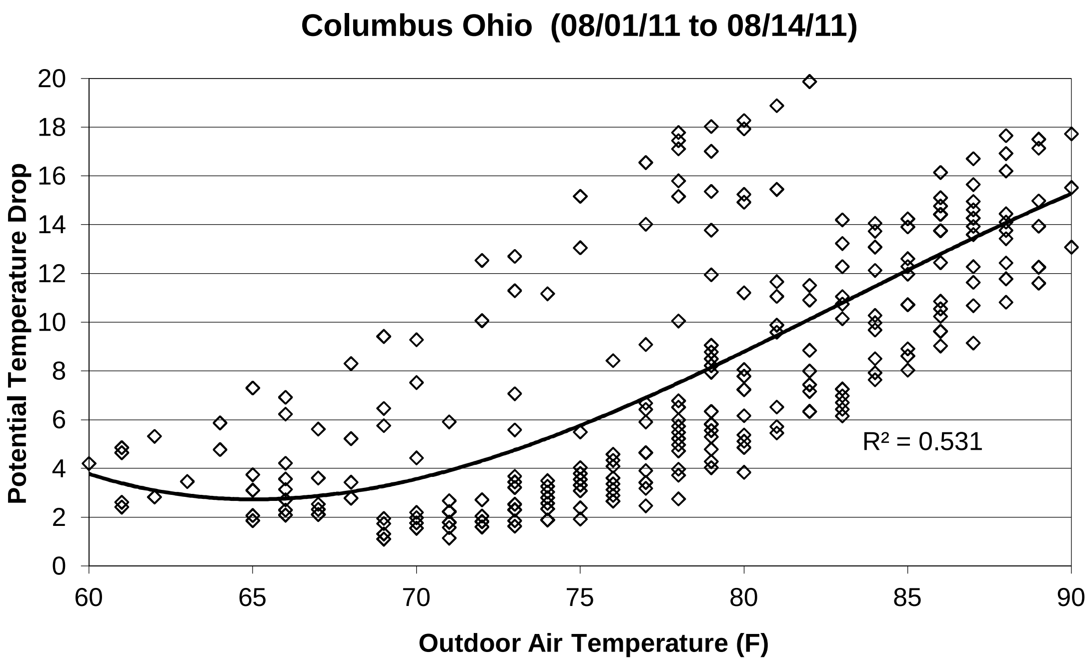

Figure 6 Potential temperature drop of the air due to an evaporative cooling system during August 1-14, 2011 in Columbus, Ohio

Weather data analyzed from three locations in Ohio indicate dairy producers in the state should initial focus on heat stress rather than cold stress. Annually, about 20 percent of the time the environmental conditions are such cows will experience heat stress as compared to only 6 percent with cold stress. Evaporative cooling systems will work in spite of the variability of the relative humidity at a given temperatures during the summer months. A low pressure sprinkler system along with adequate airflow will be critical to minimize the impact of the variability of relative humidity even if evaporative cooling systems are installed.

Opportunities with Low Profile Cross Ventilated Freestall Facilities

J. F. Smith, J. P. Harner, B. J. Bradford, and K.C. Dhuyvetter, Kansas State University
M. Overton, University of Georgia

TAKE HOME MESSAGES

- LPCV facilities have the ability to minimize fluctuations in core body temperature by providing an environment which is similar to a cow's thermoneutral zone.
- Heat stress and cold stress significantly decrease income over feed cost. Limiting environmental stress throughout the year can increase the efficiency of dairy cow feed.
- LPCV can improve pregnancy rates and reduce abortions by decreasing the impact of heat stress on reproductive performance.
- Improving a cow's environment greatly reduces the impact of heat stress on present and future milk production.

INTRODUCTION

Low profile cross ventilated (LPCV) freestall buildings are one option for dairy cattle housing. These facilities allow producers to have control over a cow's environment during all seasons of the year. As a result, an environment similar to the thermoneutral zone of a dairy cow is maintained in both the summer and winter, resulting in more stable core body temperatures. LPCV facilities allow for buildings to be placed closer to the parlor, thus reducing time cows are away from feed and water. Other advantages include a smaller overall site footprint than naturally ventilated facilities and less critical orientation since naturally ventilated facilities need to be orientated east-west to keep cows in the shade. Some of the other benefits to controlling the cow's environment include increased milk production, improved feed efficiency, increased income over feed cost, improved reproductive performance, ability to control lighting, reduced lameness, and reduced fly control costs.

CHARACTERISTICS OF LPCV FACILITIES

The "low profile" results from the roof slope being changed from a 3/12 or 4/12 pitch common with naturally ventilated buildings to a 0.5/12 pitch. Figure 1 shows the difference in ridge height between 4-row naturally ventilated buildings and an 8-row LPCV building. Contractors are able to use conventional warehouse structures with the LPCV building and reduce the cost of the exterior shell of the building, but the interior components and space per cow for resting, socializing, and feeding in an LPCV building is similar to a 4-row building. Differences in land space requirements between the 4-row naturally ventilated freestall buildings and an 8-row LPCV building are also shown in Figure 1.

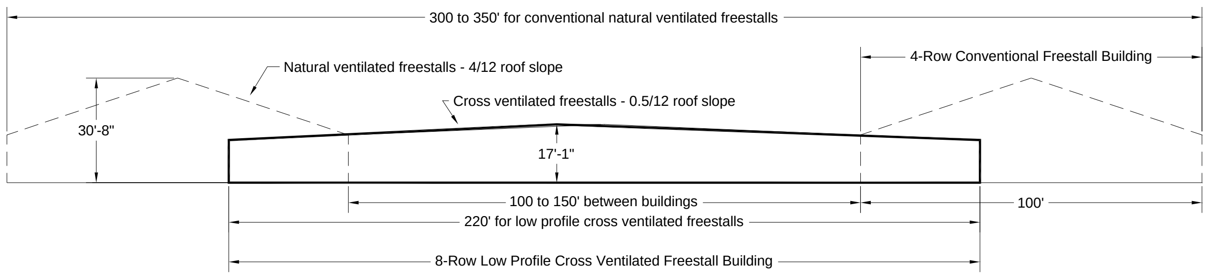

Figure 1: End Views of 8-row Naturally Ventilated Freestall Buildings and 8-row LPCV Freestall Building

Figure 2 shows an end view of an 8-row LPCV building. An evaporative cooling system is located along one side of the building and fans are placed on the opposite side. More space is available for fan placement and the cooling system parallel to the ridge rather than perpendicular because the equipment doors are located in the end walls.

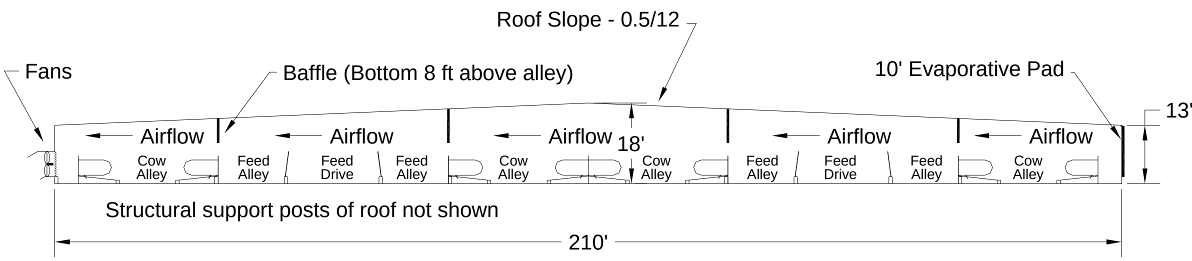

Figure 2: End View of an 8-row LPCV Freestall Building

Figure 3 shows a layout of an 8-row LPCV building with tail to tail freestalls. From a top view, this design simply places two 4-row freestall buildings side by side and eliminates the space between the buildings necessary with natural ventilation. One potential advantage of the LPCV, or tunnel ventilated, buildings is that cows are exposed to near-constant wind speeds. Inside the building the air velocity, or wind speed, is normally less than 8 miles per hour (mph) during peak airflow. The ventilation rate is reduced during cold weather with the wind speed decreasing to less than 2 mph

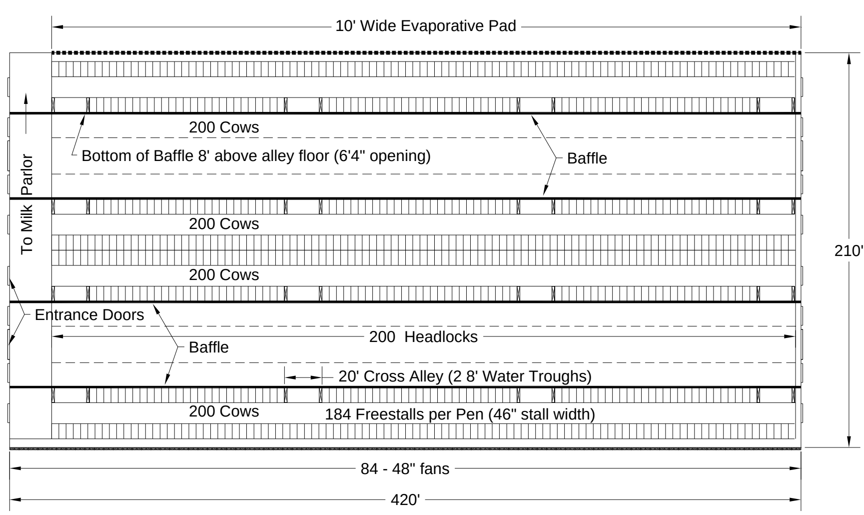

Figure 3: Top View of an 8-row LPCV Building (Adjustable Building Length Based on Cow Numbers)

PROVIDING A CONSISTENT ENVIRONMENT

Constructing a cross ventilated facility ensures the ability to provide a consistent environment year-round, resulting in improved cow performance. These buildings provide a better environment than other freestall housing buildings in the winter, spring and fall months, as well as the summer because of the use of an evaporative cooling system.

The ability to lower air temperature through evaporative cooling is dependent upon ambient temperature and relative humidity. As relative humidity increases, the cooling potential decreases, as shown in Figure 4. Cooling potential is the maximum temperature drop possible, assuming the evaporative cooling system is 100% efficient. As the relative humidity increases, the ability to lower air temperature decreases, regardless of temperature. The cooling potential is greater as air temperature increases and relative humidity decreases. Figure 4 also shows that evaporative cooling systems perform better as the humidity decreases below 50 percent.

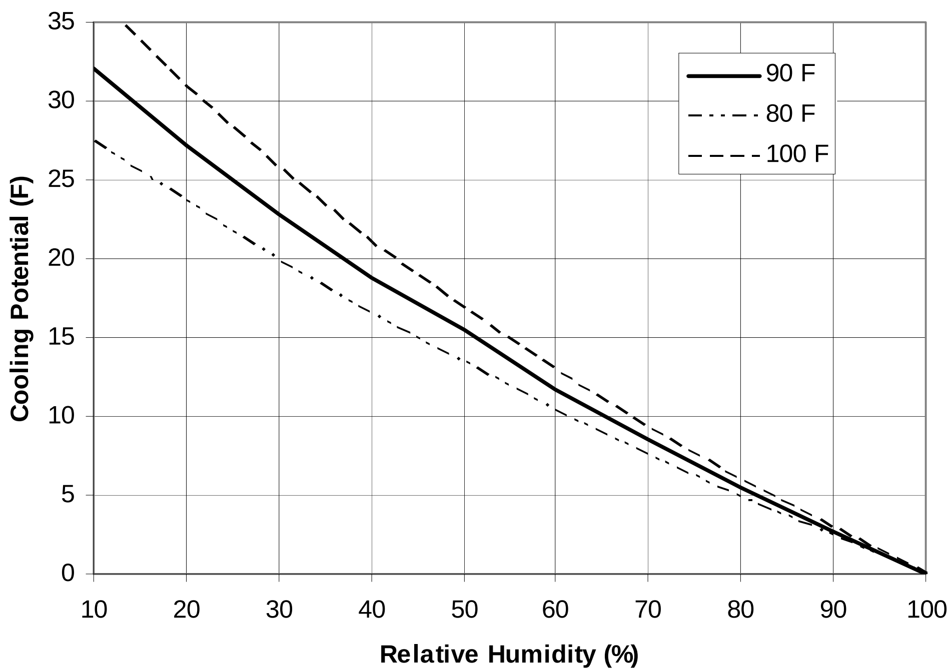

Figure 4: Impact of Relative Humidity and Temperature on Cooling Potential When Using an Evaporative Cooling System

LPCV DATA

Data loggers were used to evaluate the ability of an LPCV system to reduce heat stress under different environmental conditions. Temperature data collected shows the limitations of the evaporative cooling system to improve the environment inside the structure during periods of high humidity. Ambient barn intake and barn exhaust temperature, relative humidity, and temperature humidity index (THI) for 4 different days (July 1, 4, 26, and 29, 2006) with various conditions are presented in Figures 5 through 16. Temperature reduction using evaporative pads is compromised when humidity is high. Individual climates should be evaluated so realistic expectations can be set on how well the evaporative cooling system will improve the summer environment. Further research is needed to investigate the combination of soakers and evaporative cooling to reduce potential heat stress during periods of high relative humidity and high temperatures.

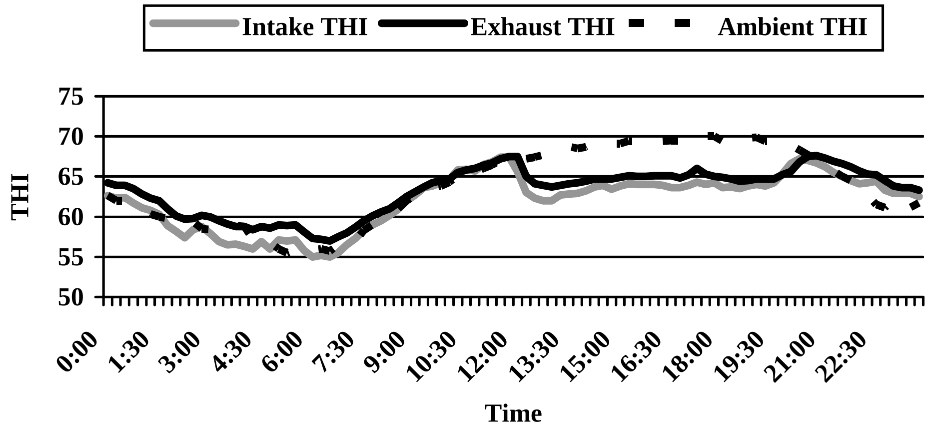

Figure 5: Cool Summer Conditions, Temperature (F) (7-4-06)

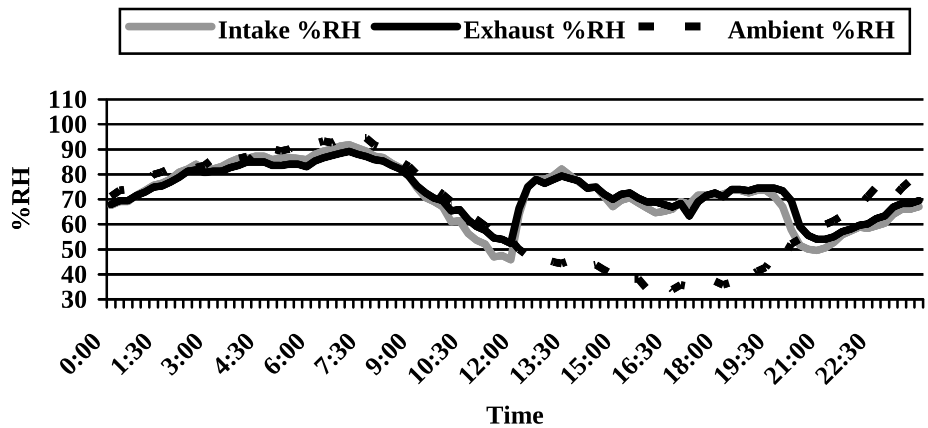

Figure 6: Cool Summer Conditions, Percentage of Relative Humidity (% RH) (7-4-06)

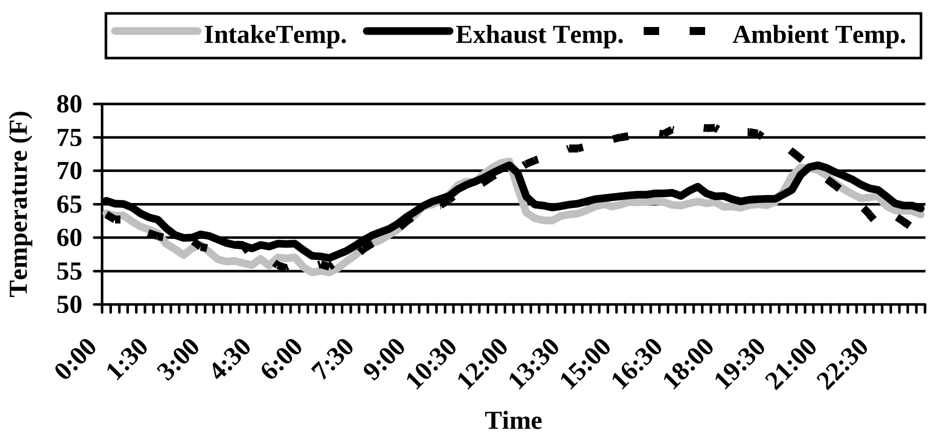

Figure 7: Cool Summer Conditions, THI (7-4-06)

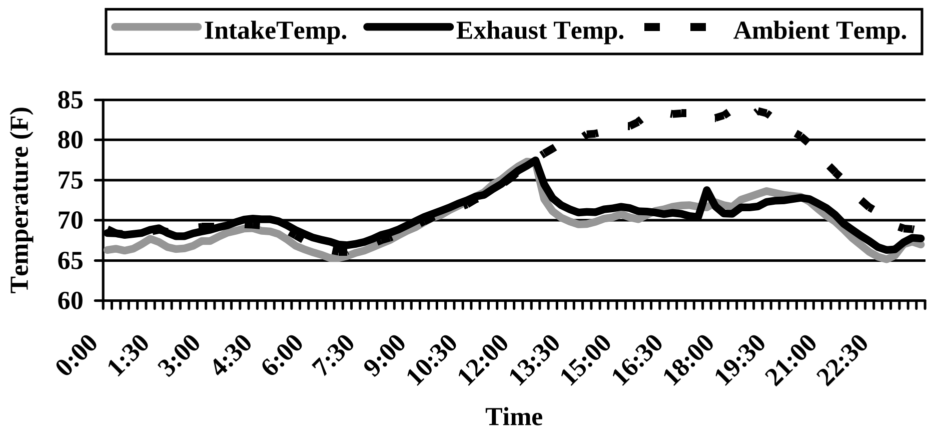

Figure 8: Average Summer Conditions (7-1-06)

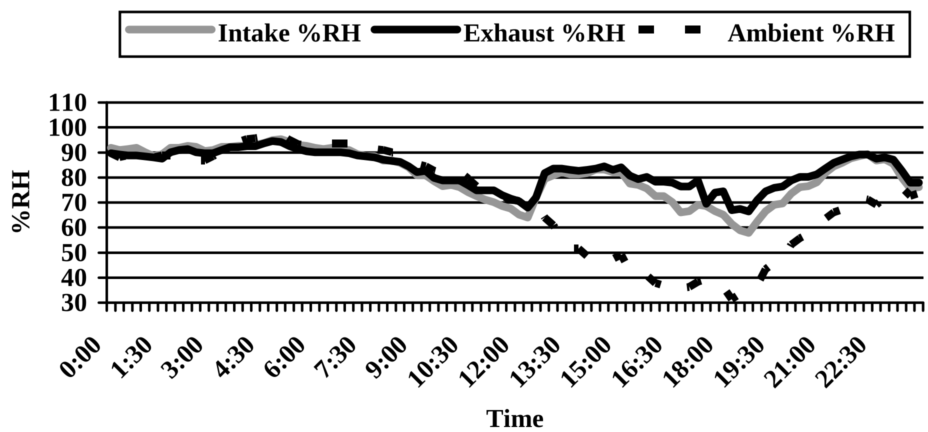

Figure 9: Average Summer Conditions, % RH (7-1-06)

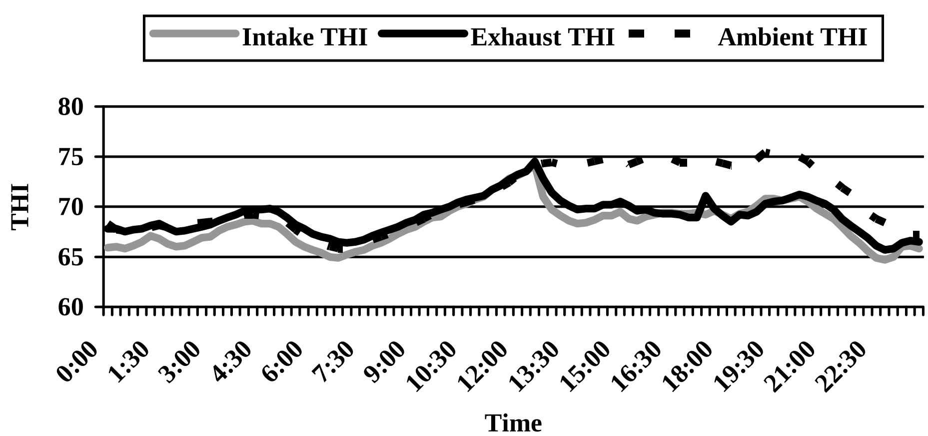

Figure 10: Average Day, THI (7-1-06)

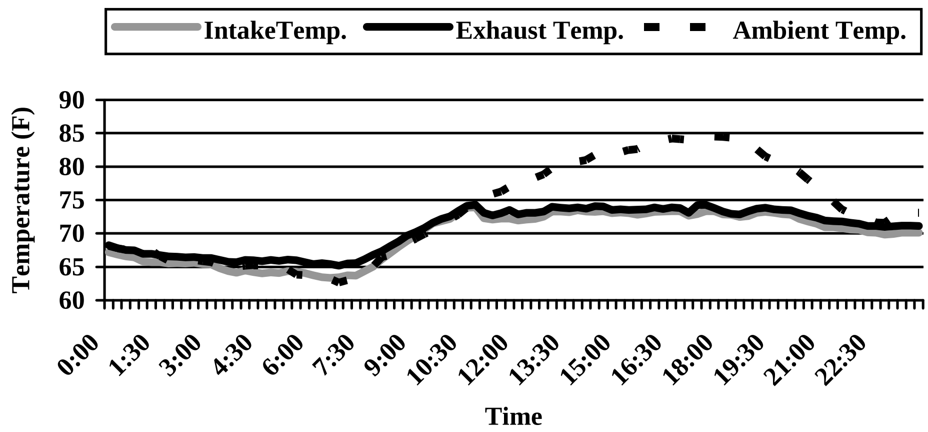

Figure 11: Humid Day Temperature (7-26-06)

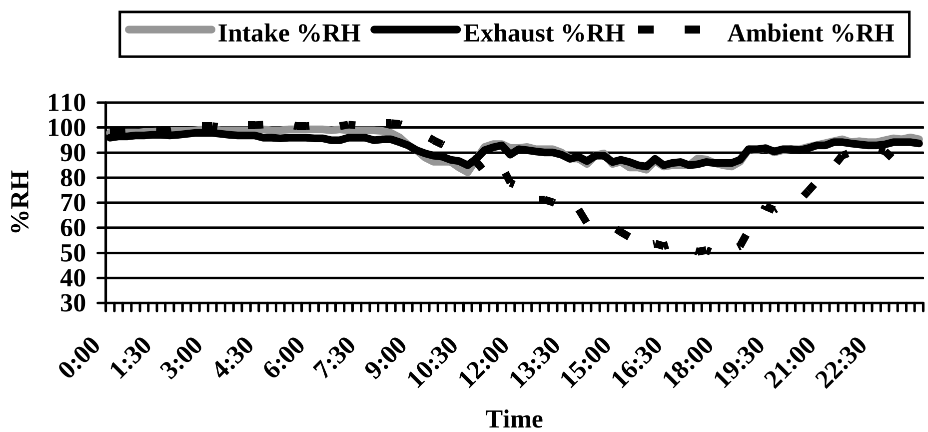

Figure 12: Humid Day Relative Humidity, % RH (7-26-06)

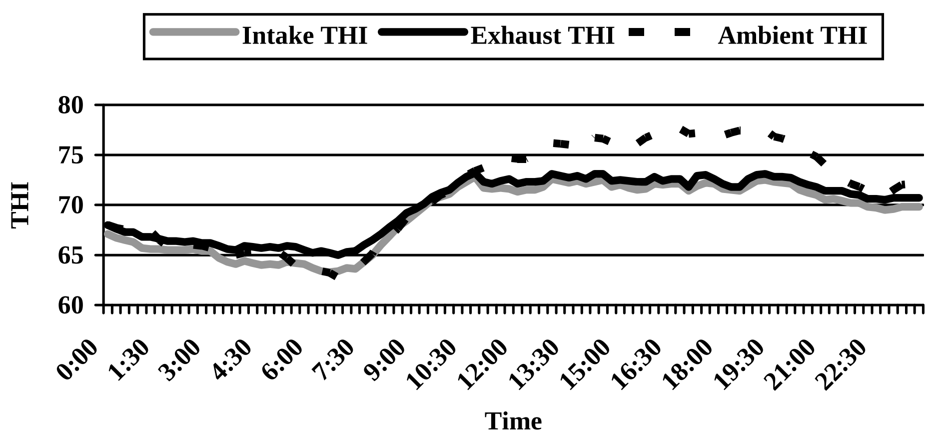

Figure 13: Humid Day, THI (7-26-06)

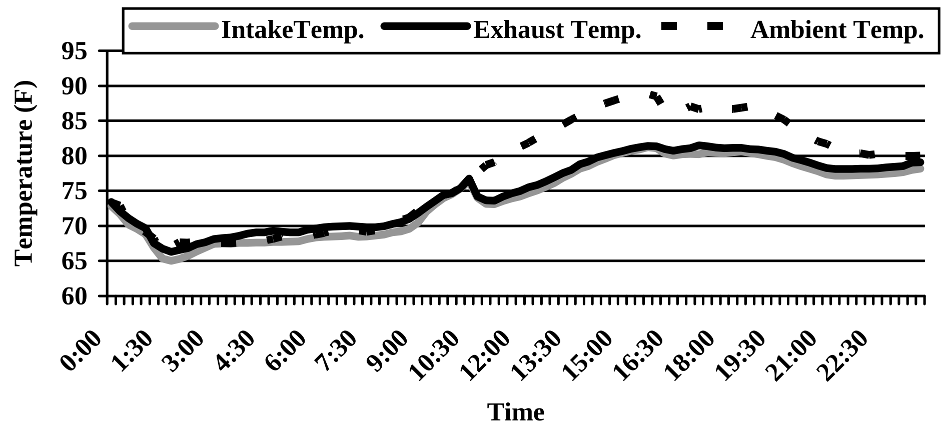

Figure 14: Very Humid Day Temperature (7-29-06)

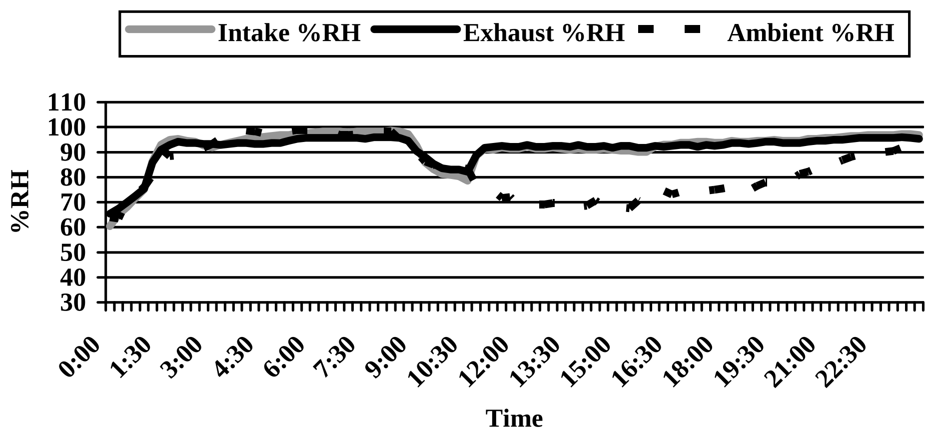

Figure 15: Very Humid Day, %RH (7-29-06)

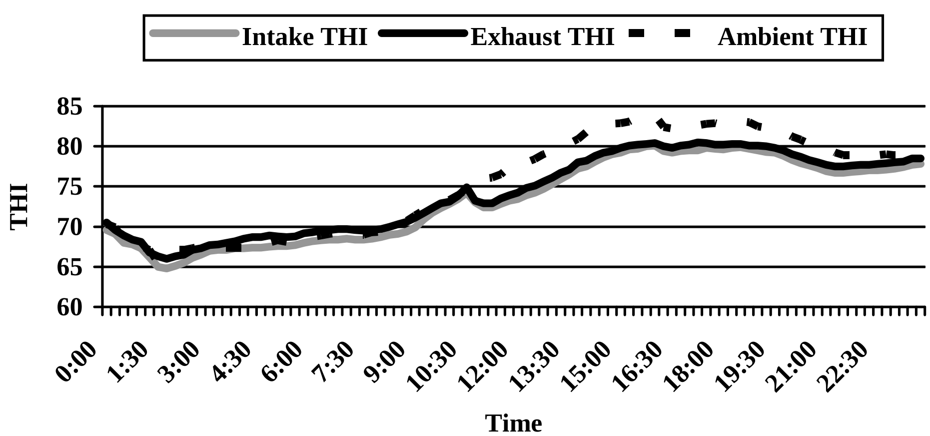

Figure 16: Very Humid Day, THI (7-29-06)

IMPACT OF LPVC FACILITIES AND CORE BODY TEMPERATURE

One of the major benefits of LPCV facilities is the ability to stabilize a cow's core body temperature. A heat stress audit was conducted on a North Dakota dairy to evaluate the impact of a changing environment on the core body temperature of cows. Vaginal temperatures were collected from 8 cows located in the LPCV facility and 8 cows located in a naturally ventilated freestall facility with soakers and fans. Data was recorded every 5 minutes for 72 hours using data loggers (HOBO® U12) attached to a blank CIDR® (Brouk 2005). Environmental temperature and humidity data were collected on individual dairies utilizing logging devices which collected information at 15 minute intervals. The environmental conditions and vaginal temperatures during the evaluation period are presented in Figures 17 and 18. Vaginal temperatures were acceptable in both groups, but the temperatures of cows housed in the LPCV facility were more consistent. Feedline soakers in naturally ventilated buildings are effective in cooling cows, but they require the cows to walk to the feedline to be soaked. On the other hand, cows in an LPCV facility already experience temperatures that are considerably lower than the ambient temperature. Reducing the fluctuations in core body has a dramatic impact on the production, reproduction and health of a dairy cow.

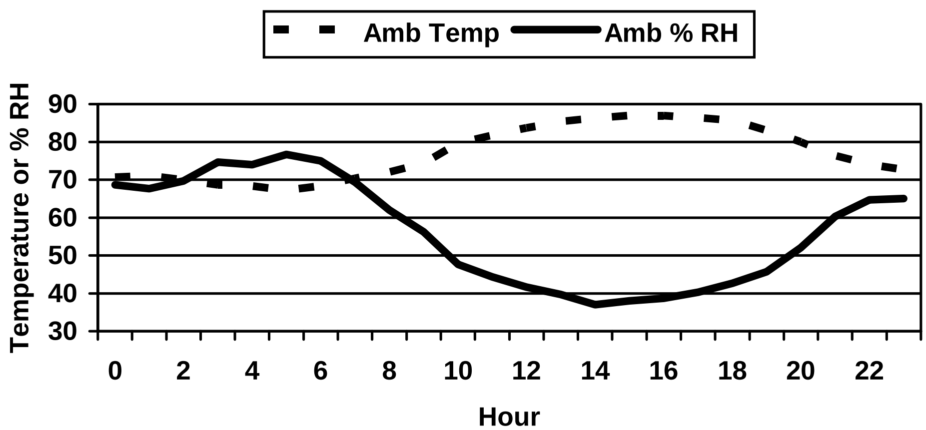

Figure 17: Ambient Temperature and % RH for Milnor, ND (July 6-9, 2006)

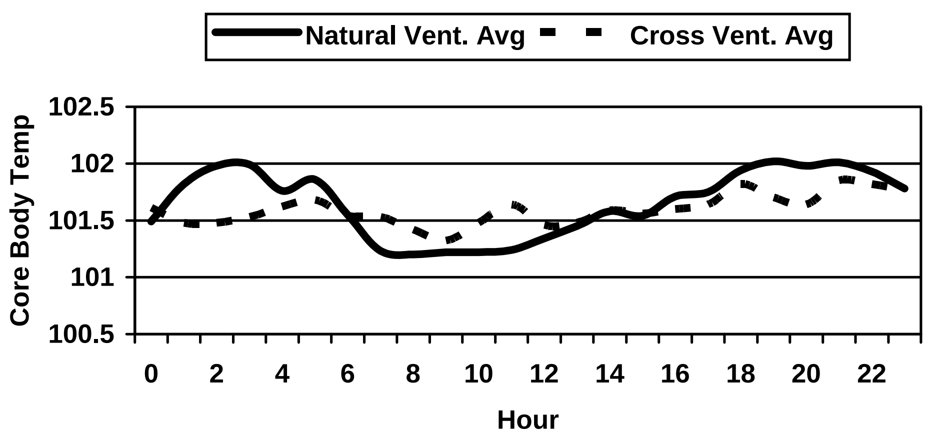

Figure 18: Core Body Temperature of Cows Housed in Naturally Ventilated (Fans & Soakers) and LPVC Freestalls (Evaporative Pads)

ENVIRONMENTAL IMPACT ON NUTRIENT REQUIREMENTS AND EFFICIENCY

Dairy cows housed in an environment beyond their thermoneutral zone alter their behavior and physiology in order to adapt. These adaptations are necessary to maintain a stable core body temperature, but they affect nutrient utilization and profitability on dairy farms.

The upper critical temperature, or upper limit of the thermoneutral zone, for lactating dairy cattle is estimated to be approximately 70 - 80°F (NRC, 1981). When temperatures exceed that range, cows begin to combat heat stress by decreasing feed intake (Holter at el., 1997), sweating, and panting. These mechanisms increase the cows' energy costs, resulting in up to 35% more feed necessary for maintenance (NRC, 1981). When dry matter intake decreases during heat stress, milk production also decreases. A dairy cow in 100°F environment decreases productivity by 50% or more, relative to thermoneutral conditions (Collier, 1985).

Compared to research on the impact of heat stress, little attention has been spent on cold stress in lactating dairy cattle. The high metabolic rate of dairy cows makes them more susceptible to heat stress in U.S. climates, so, as a result, the lower critical temperature of lactating dairy cattle is not well established. Estimates range from as high as 50°F (NRC, 1981) to as low at -100°F (NRC, 2001). Regardless, there is evidence that the performance of lactating cows decreases at temperatures below 20°F (NRC, 1981). One clear effect of cold stress is an increase in feed intake. While increased feed intake often results in greater milk production, cold-induced feed intake is caused by an increase in the rate of digesta passage through the gastrointestinal tract. An increased passage rate limits the digestion time and results in less digestion as the temperature drops (NRC, 2001). In cold temperatures, cows also maintain body temperature by using nutrients for shivering or metabolic uncoupling, both of which increase maintenance energy costs. These two mechanisms decrease milk production by more than 20% in extreme cold stress. However, even when cold stress does not negatively impact productivity, decreased feed efficiency can hurt dairy profitability.

To assess the effects of environmental stress on feed efficiency and profitability, a model was constructed to incorporate temperature effects on dry matter intake, diet digestibility, maintenance requirements, and milk production. Expected responses of a cow producing 80 pounds of milk per day in a thermoneutral environment with Total Mixed Ration (TMR)costs of $0.12/lb dry matter and milk value of $18/ hundred weight of milk (cwt) are shown in Figure 19. The model was altered to assess responses to cold stress if milk production is not decreased. In this situation, the decrease in diet digestibility results in an 8% decrease in income over feed cost as temperatures drop to -10°F ($6.94 vs. $7.52/cow per day).

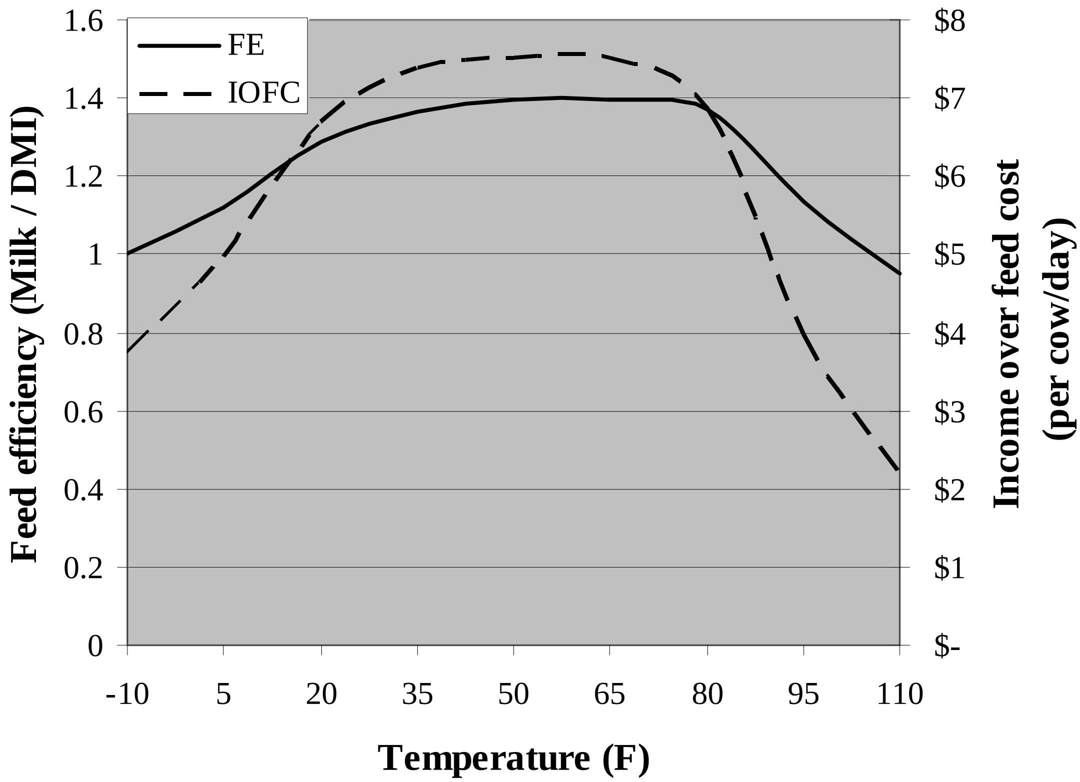

Figure 19: Responses to Environmental Stress, (Thermoneutral Production of 80 lbs/day, TMR Cost of $0.12/lb Dry Matter, and Milk Value of $18/cwt)

With these research results, cost benefits can be estimated for environmental control of LPCV facilities. Benefits of avoiding extreme temperatures can be evaluated by comparing returns at ambient temperatures to temperatures expected inside LPCV barns. For example, the model above predicts that income over feed cost can be improved by nearly $2 per cow/day if the ambient temperature is 95°F and barn temperatures are maintained at 85°F. Likewise, if ambient temperature is 5°F and the temperature inside the barn is 15°F, income over feed cost is expected to increase by $1.15 per cow/day.

Besides effects on feed costs and productivity, heat stress also has negative effects on reproduction, immunity, and metabolic health. These factors represent huge potential costs to a dairy operation. While responses to cold stress are not typically dramatic, increased manure production is a resulting factor. In this model, increased feed intake and decreased digestibility during cold stress also increased manure output by as much as 34%. This is a significant cost factor on many farms, requiring increased manure storage capacity and more acres for manure application.

ENVIRONMENTAL IMPACT ON REPRODUCTION

Even though cold stress has little effect on reproduction, heat stress can reduce libido, fertility, and embryonic survival in dairy cattle. Environmental conditions above a dairy cow's thermoneutral zone decreases ability to dissipate heat and results in increased core body temperature. The elevated body temperatures negatively impact reproduction, both for the female and the male.

The impact of heat stress can be categorized by the effects of acute heat stress (short-term increases in body temperature above 103^{o} F) or chronic heat stress (the cumulative effects of prolonged exposure to heat throughout the summer). In acute heat stress, even short-term rises in body temperature can result in a 25 – 40% drop in conception rate. An increase of 0.9^{o} F in body temperature causes a decline in conception rate of 13% (Gwazdauskas et al.). The impact of heat stress on reproduction is more dramatic as milk production increases, due to the greater internal heat load produced because of more feed intake (al-Katanani et al., 1999).

Declines in fertility are due, at least in part, to damage of developing follicles because of a lower production of the follicular hormone, estradiol. As a consequence, lower quality, aged follicles are ovulated and the resulting conception rate is decreased (Wolfenson, et al.). The lower estradiol levels also make it more difficult to find cows in heat, since a high level of estradiol is required for a cow to express heat or stand to be mounted. In herds that utilize artificial insemination (AI) and depend entirely on estrus detection, or the expression of cows in heat, heat detection decline by 10-20% is common during the summer months. Timed AI tends to result in a greater percentage of inseminations during the summer months as a consequence of the difficulty in finding cows in heat.

If, despite the reduced follicular quality, cows manage to become pregnant, a greater likelihood exists of embryonic loss due to heat stress. Many times, cows actually achieve ovulation and fertilization, but early embryonic loss often occurs during days 2 to 6 post-insemination and the observer believes that the cow never actually conceived.

The results of chronic heat stress are more severe in that there results a poor quality corpora lutea, which produces low levels of progesterone. As a consequence, fertility is negatively affected and a greater risk of twins exists for cows that get pregnant toward the latter periods of heat stress. The risk of late embryonic loss and abortion is approximately 2 to 2.5 times greater for cows bred during and immediately following heat stress. Chronic heat stress also greatly depresses feed intake and prolongs the period of time required for a cow to reach positive energy balance, thus causing excessive weight loss and delaying days to the first ovulation. Because of the severe challenges of impregnating cows during the summer, some herds decrease their efforts during that time.

Whether the decline in pregnancy rates is voluntary or not, drops in the number of cows that become pregnant create holes in the calving patterns. Often, there is a rebound in the number of cows that become pregnant in the fall. Nine months later, a large number of pregnant cows puts additional pressures on the transition facilities when an above-average group of cows moves through the close-up and fresh cow pens. Overcrowding these facilities leads to increases in post-calving health issues, decreased milk production, and impaired future reproduction.

Table 1 examines the economic impact of heat stress by describing the reproductive performance for a hypothetical 3200 cow Holstein dairy.

Table 1. Historical Reproductive Performance for a Hypothetical 3200 Cow Holstein Dairy						
Date	**# Eligible**	**Insemination Risk**	**# Bred**	**Conceptio n Risk**	**# Preg**	**Pregnancy Rate**
1-Jan	932	57%	531	30%	159	17%
22-Jan	905	57%	516	30%	155	17%
12-Feb	884	57%	504	30%	151	17%
5-Mar	868	57%	495	30%	149	17%
26-Mar	855	57%	487	30%	146	17%
16-Apr	845	57%	481	30%	144	17%
7-May	833	57%	475	30%	142	17%
28-May	831	57%	473	30%	142	17%
18-Jun	825	**46%**	376	**21%**	79	**10%**
9-Jul	883	**46%**	402	**21%**	85	**10%**
30-Jul	930	**46%**	424	**21%**	89	**10%**
20-Aug	983	**46%**	448	**21%**	94	**10%**
10-Sep	1041	**49%**	514	**24%**	123	**12%**
1-Oct	1078	54%	582	30%	175	16%
22-Oct	1049	57%	598	30%	179	17%
12-Nov	1014	57%	578	30%	173	17%
3-Dec	965	57%	550	30%	165	17%
24-Dec	945	57%	539	30%	162	17%
	16664	**54%**	**8974**	**28%**	**2513**	**15%**

As shown in Table 1, the herd has above-average reproductive performance through much of the year (insemination risk of 57%, conception rate of 30% and a pregnancy rate of 17%). However, during the summer season, as well as throughout the month of September, both insemination risk and conception rate decline, resulting in pregnancy rates that are well below average. As a consequence of these periods of poor reproductive performance, the herd's annual pregnancy rate is 15%. Based on economic models that evaluate the value of changes in reproductive performance, this subpar performance during the five 21-day periods costs the dairy approximately $115,000 (Overton, 2006).

While this simple spreadsheet illustrates how heat stress adversely affects reproductive performance, it does not capture the total cost of the issues created by heat stress. Consideration of the increased number of abortions commonly seen during heat stress, the impact of transition facility overcrowding, the negative affect on cow health, early lactation milk production, and future reproduction leads to estimated losses well beyond $135,000 per year, or at least $42/ cow/ year, using a milk price of $0.18 and a feed cost of $0.12.

ENVIRONMENTAL IMPACT ON MILK PRODUCTION

Though the impact of cold stress on milk production is minimal, the impact of heat stress on milk production can be very dramatic. Numerous studies have been completed to evaluate the economic impact of heat stress on milk production (Dhuyvetter et al., 2000), but because so many approaches are used to manage heat stress, standard evaluations are difficult. Heat stress not only impacts milk production during summer months, but it also reduces the potential for future milk production of cows during the dry period and early lactation. For every pound of peak milk production that is lost, an additional 250 pounds of production will be lost over the entire lactation.

A simple sensitivity analysis was conducted to observe the impact of heat stress on gross income. A net milk price of $18/cwt was used for this analysis. The milk production impact of 90-150 days of heat stress on gross income per cow is presented in Table 2. When daily milk production is reduced 2 to 12 pounds per day per cow, the gross income loss related to heat stress ranges from $32.40 to $324.00 per cow.

Table 2. Potential Loss of Gross Income for Different Lengths of Heat Stress

Reduction of Milk Production (lbs/cow/day)	90 Days of Lost Production (lbs)	120 Days of Lost Production (lbs)	150 Days of Lost Production (lbs)	Lost Income 90 Days ($.18/lb)	Lost Income 120 Days ($.18/lb)	Lost Income 150 Days ($.18/lb)
2	180	240	300	$32.40	$43.20	$54.00
4	360	480	600	$64.80	$86.40	$108.00
6	540	720	900	$97.20	$129.60	$162.00
8	720	960	1200	$129.60	$172.80	$216.00
10	900	1200	1500	$162.00	$216.00	$270.00
12	1080	1440	1800	$194.40	$259.20	$324.00

The impact of heat stress on future milk production is evaluated in Table 3. Gross income per cow per lactation is increased from $90 to $540 per cow/lactation as peak milk production is increased from 2 to 12 lbs/cow/day during periods of heat stress.

Table 3. Impact of Increasing Peak Milk During Heat Stress on Future Milk Production and Gross Income

Increase in Peak Milk Production (lbs/cow/day)	Additional Milk Production (lbs/lactation)	Additional Gross Income per Lactation ($.18/lb)
2	500	$90.00
4	1000	$180.00
6	1500	$270.00
8	2000	$360.00
10	2500	$450.00
12	3000	$540.00

LIGHTING

Light is an important environmental characteristic in dairy facilities. Proper lighting can improve cow performance and provide a safer and more pleasant work environment. Meeting the lighting requirement of both dry and lactating cows in an LPCV facility can be challenging, though, because lactating and dry dairy cattle have different lighting requirements. Dry cows need only 8 hours of light per day and 16 hours of darkness, while lactating dairy cows that are exposed to 16 hours of continuous light (16L) increase milk production from 5 to 16% (8% being typical), increase feed intake about 6%, and maintain reproductive performance (Peters et al., 1978, 1981; Piva et al., 1992). It is important to note, though, that 16L does not immediately increase milk production. A positive response can take two to four weeks to develop (Tucker, 1992; Dahl et al., 1997), assuming that nutrition and other management conditions are acceptable. However, cows exposed to 8 L versus 16 L during the dry period produce 7 lbs/day more milk in the following lactation (Miller et al., 2000).

Enhanced lighting for the milking herd is profitable (Dahl et al., 1997; Chastain and Hiatt, 1998). Producers report that increased light improves cow movement, observation, and care. Cows move more easily through uniformly lit entrances and exits, and herdsmen, veterinarians, and other animal care workers report easier and better cow observation and care. Workers also note that a well-lit area is a more pleasant work environment. Increased cow performance and well-being, plus better working conditions make lighting an important environmental characteristic in a dairy facility.

SUMMARY

LPCV facilities are capable of providing a consistent environment for dairy cows throughout the year. Changing the environment to reflect the thermoneutral zone of a dairy cow minimizes the impact of seasonal changes on milk production, reproduction, feed efficiency and income over feed cost. The key is to reduce variation in the core body temperature of the cows by providing a stable environment.

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An Overview of Dairy Manure Nutrients

Joe Harner and Micheal Brouk[1]

Management of manure nutrients on any livestock enterprise is becoming a major issue. Operations are seeking ways to add value to the manure nutrients while minimizing the cost of handling manures. Table 1 shows the manure nutrients excreted for a lactating dairy cow based on daily milk production. The table was developed using a simplified equation being included in the revised manure excretion standard of the American Society of Agricultural Engineers. As milk production increases, manure excreted and manure nutrients increase linearly. As milk production approaches 0 lbs/cow/day, manure production still remains at 95 lbs/cow/day for a 1,400 lb cow or 68 lbs per 1,000 lbs live weight. This manure excretion is similar to beef cattle estimated at 60 lbs/day per 1,000 lbs live weight. Table 1 shows an increase in manure nutrients as milk production increases.

Table 1. Excreted manure characteristics based on daily milk production per cow.

Milk Production lbs/cow/day	Total Manure Production lbs/cow/day	Manure Nutrients Excreted (lbs/cow/dy)			Moisture Content (percent)
		Nitrogen	Phosphate	Potash	
50	127	0.83	0.32	0.16	87.5
60	134	0.88	0.34	0.18	87.4
70	140	0.92	0.36	0.19	87.3
80	147	0.96	0.38	0.21	87.2
90	153	1.00	0.40	0.23	87.1

Beef operations typically only consider the excreted manure waste stream on a daily basis. A dairy has two main waste streams – the excrete manure waste stream and the milk parlor wash water. Table 2 shows the influence of water usage in the milk parlor on the overall waste stream on a dairy with milk production at 70 lbs/cow/day. In Kansas, water allocations are based on 100 gallons per cow per day in the milk parlor. The total quantity of material that has to be handled increases from 140 lbs of excrete manure to 970 lbs when the parlor wash water is included. This reduces the solids content of the waste stream from 12.7 to 1.8 percent. Thus, the overall daily waste stream per 1,000 lbs live weight equals 700 lbs on a dairy as compared to 60 lbs on a beef operation. There are differences in lagoon volumes between dairies and feedlots for volume required to handle normal rainfall events. Feedlots are typically sized based on 150 to 250 sq ft per 1,000 lbs live weight and dairies are sized based on 350 to 500 sq ft per 1,000 lbs. These differences are not considered major in the High Plains region since evaporation handles

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most of the excrete urine and rainfall events. Evaporation results in the manure being harvested from a beef feedlot being relatively dry, i.e. less than 40 percent in most cases. Manure harvested from dry lot dairies will have a similar moisture content while manure separated from the waste stream on free stall dairies will generally have a moisture content of 80 percent or more. Thus the main waste streams from a beef feedlot are low moisture while the waste stream from a dairy is high moisture in nature.

Table 2. The influence of parlor water usage on waste stream on a dairy with lactating cows milking 70 lbs per cow per day.

Water Usage in Parlor gal/cow/day	Quantity of Waste Stream (lbs/cow/day)			Total Solids in Stream (percent)	Ratio of Waste to Milk
	Parlor Water	Excreted Manure	Total Weight		
Excreted	0	140	140	12.7	2
50	415	140	555	3.2	7.9
60	498	140	638	2.8	9.1
70	581	140	721	2.5	10.3
80	664	140	804	2.2	11.5
90	747	140	887	2.0	12.7
100	830	140	970	1.8	13.9
110	913	140	1,053	1.7	15.1
120	996	140	1,136	1.6	16.2
Beef (1,000 lbs)	0	60	60	12	NA

Figure 1 shows a comparison or nutrient values between dry lot and free stall dairies and beef lot operations. The data is based on limited sampling of dairies in Kansas with the beef feedlot information being obtained from Sevi-Tech Labs. The dry lot and free stall dairies were flushing the milk parlor. The table shows the nutrient value of the lagoon water ($/1,000 gallons) was much higher on free stall dairies as compared to dry lot dairies. In fact, there was little difference between nutrient value in the lagoons of dry lot dairies and beef feedlots. The data also shows the nutrient value of the solid waste stream ($/wet ton) was much higher for beef feedlots and lowest for free stall dairies. The recycled flush water absorbs nutrients from the solids each time an alley is flushed. This increases the nutrient content of the lagoon water. Other data shows even more differences in nutrient contents of the lagoons when comparing flush versus non flush milk parlors on dairies. The non flush parlor dairies have much lower nutrient content in the lagoon and high nutrient contents in the solids basins.

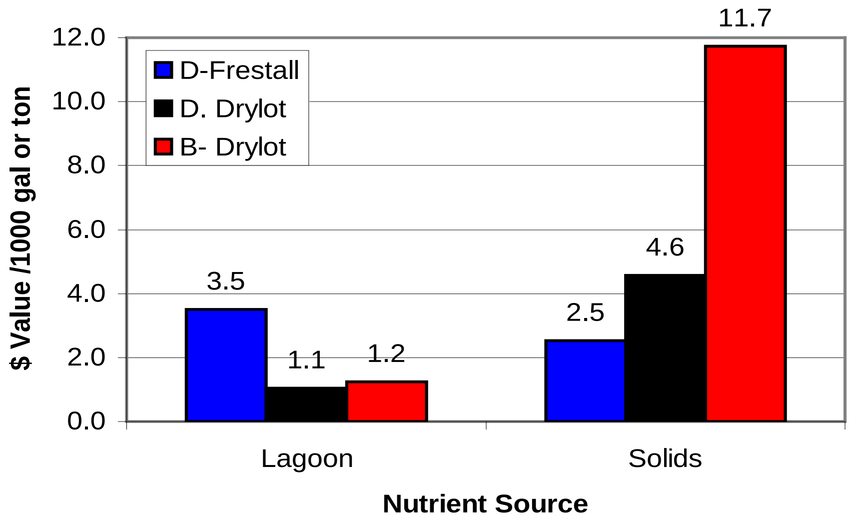

Figure 1. Comparison of economic value of waste stream from free stall and dry lot dairies and beef operations. Nitrogen was assumed to equal $0.25/lb, phosphate $0.16/lb and potash $0.14/lb.

Figure 2 shows the economic value of the manure if applied to cropland with high soil phosphorus levels. In this case, the value of the phosphorus nutrients in the manure steams is equal to zero since supplemental phosphate is not required. The value of the nutrients in the lagoon water is reduced by about 20 percent for the dairy operations but there is no change in the value of the nutrients from the beef feedlot lagoons. Phosphorus tends to be in the solids portion of the waste stream. The value of the nutrients in the solids portion of the waste streams reduces by nearly 25 percent for free stall dairies, 30 percent for dry lot dairies and nearly 40 percent for the beef feedlots when comparing Figures 1 and 2.

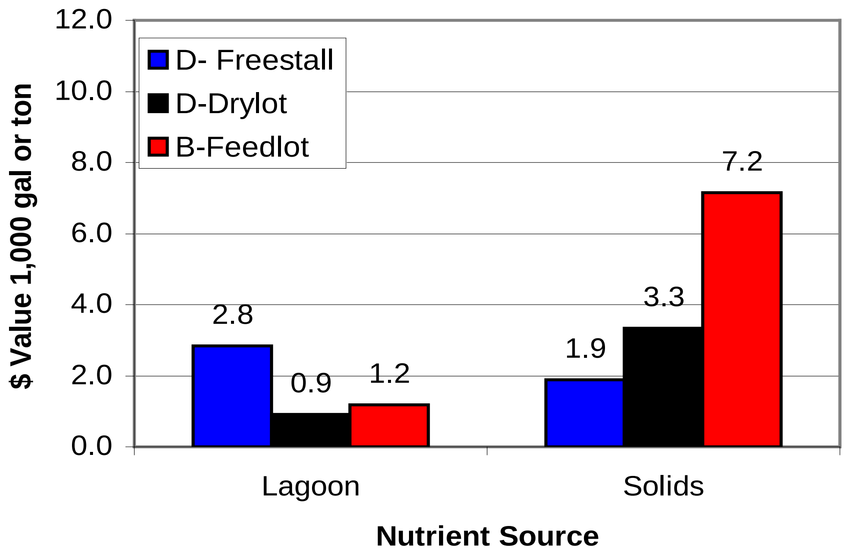

Figure 2. . Comparison of economic value of waste stream from free stall and dry lot dairies and beef operations assuming value of phosphate is zero. Nitrogen was assumed to equal $0.25/lb and potash $0.14/lb.

Using the data available, Figure 3 shows a nutrient's percent contribution to the overall nutrient value. For example, 40 percent of the value for the lagoon nutrients is derived from potash, 11 percent for phosphate and 49 percent from nitrogen on free stall dairies. This compares to beef feedlots where 70 percent of the value is derived from potash and only 27 percent from nitrogen.

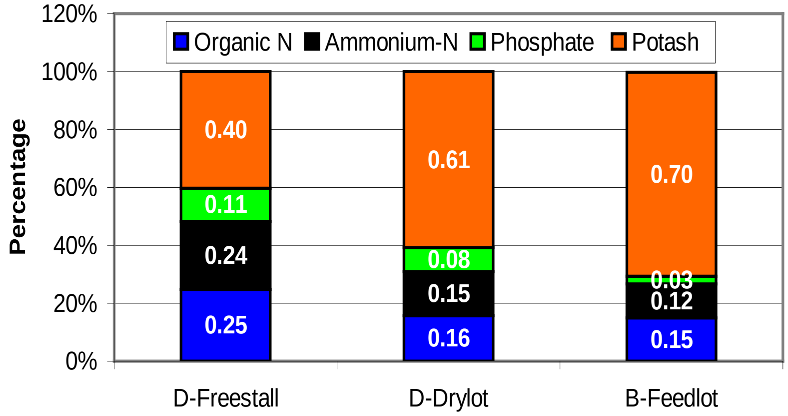

Figure 3. Comparison of percent nutrient value of different nutrients in the lagoon waste stream

Figure 4 shows a nutrient's percent contribution to value of the solids. For example, 17 percent of the value for the lagoon nutrients is derived from potash over 68 percent from nitrogen on free stall dairies. This compares to beef feedlots where 32 percent of the value is derived from potash and 39 percent from nitrogen. The dry lot dairy has similar percentage contribution to nutrient value to the beef feedlot.

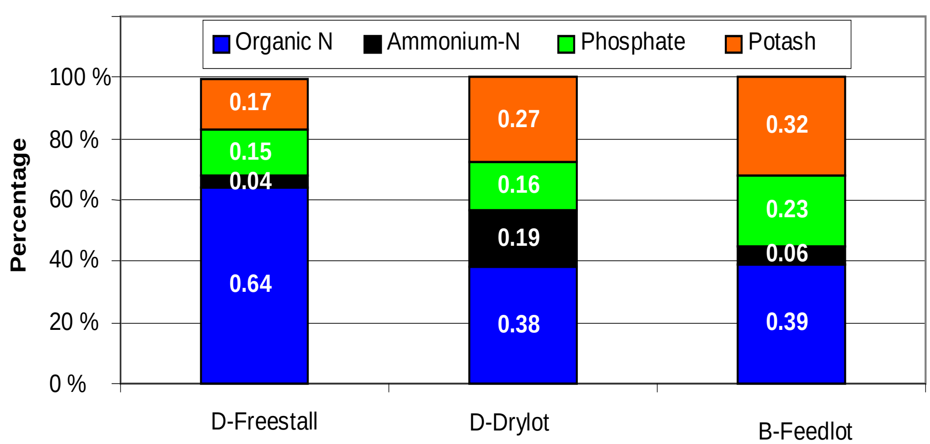

Figure 4. Comparison of percent nutrient value of different manure nutrients in the solids waste stream

Figure 5 compares the economic value of manure based on a dry weight bases. The figure shows the nutrient value of solids from a dry lot dairy equal about $0.0087 per lb (dry basis) as compared to $0.0075 for beef feedlots and $0.0065 for free stall dairies.

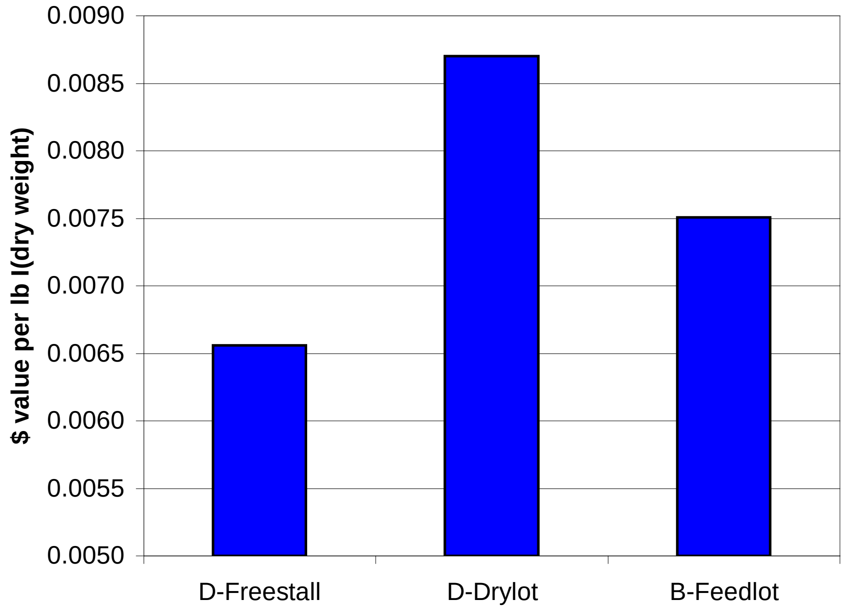

Figure 5. Manure nutrient value from different types of livestock enterprises compared on a dry basis.

Comprehensive nutrient management plans basically match manure nutrients to crop nutrient utilization. Table 3 shows the influence of milk production on land requirements based on different limiting nutrients for a 1,000-cow dairy. The table assumes crop nitrogen, phosphate and potash requirements at 200, 80 and 200 lbs per acre, respectively. It was also assumed that 50 percent of excreted volatized to the atmosphere. The table shows that if phosphate (phosphorus) is the limiting nutrients and requires 2, 5 and 3 times as much land as compared to nitrogen, potash (potassium) and water, respectively. Table 3 highlights the need to first consider the importance of ration formulation and eliminating excess phosphorus in the diet. Any excess phosphorus in the diet is excreted and results in additional land requirements if phosphorus is the limiting nutrient.

Many dairies in southwest Kansas are dry lot dairies. Typical space allocations are 500 to 700 square feet per cow per day. Based on an annual net evaporation rate of 36 inches, 250 square feet of lot space is required to evaporate the120 lbs of urine. About 100 square feet is required to evaporate the urine from beef cattle. The challenge remains is the 100 gallons of water usage in the milk parlor. Assuming a 1,000 cow dairy and 100 gallons per day in the parlor, it only requires 10 days of parlor water to equal the amount of water evaporated from a 1 acre lagoon losses 3 feet per year. The remainder of the water used throughout the year must be dealt with in another manner.

Table 3. Acres of cropland required for land application of excreted nutrients and parlor wash water from a 1,000-cow dairy assuming crop nutrient uptake is 200, 80 and 200 lbs/acre for nitrogen, phosphate and potash, respectively.

Milk Production	Acres Required Based on 100 percent Utilization of Manure Nutrients Annually			
	Nitrogen	Phosphate	Potash	Water*
50	761	1,476	290	532
60	800	1,558	323	546
70	838	1,639	355	569
80	877	1,721	388	592
90	915	1,802	421	615

*Water based on 100 gallons/cow/day in parlor and assumes application rate is 2 feet per acre.

Determining the real value of manure from a dairy requires consideration of the water component. One dairy cow uses 1/10 acre-ft of water in the milk parlor annually. For every 20 cows, there is enough water to apply 2 acre-ft of water to an acre of cropland. This water quantity is based on using 100 gallons per cow per day in the milk parlor. Dairies with free stall housing need to recover the manure nutrient value within the lagoon.

Modifications to KSU Maternity Building

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Introduction

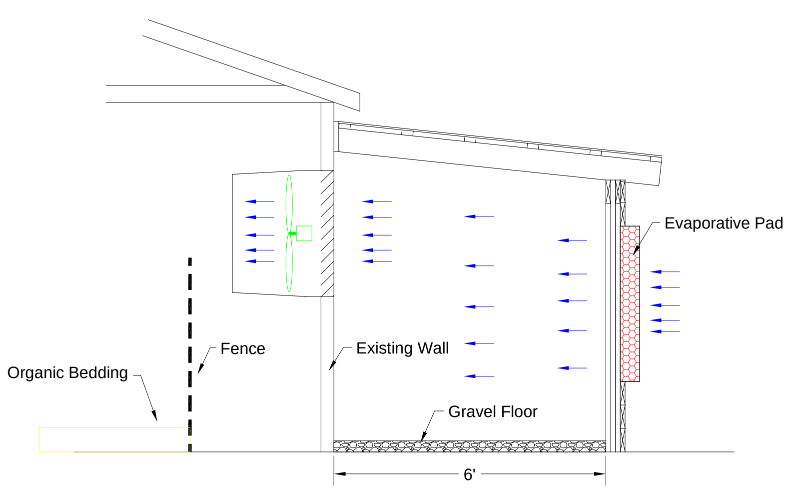
Dairy facilities at Kansas State University were constructed during the 1960's and 70's. Many of the buildings were constructed with low roof lines and minimal natural ventilation. Heat abatement procedures, including shade and sprinklers over the feed line along with increasing natural ventilation within the stall area, have been incorporated in the lactating cow pens. Additional shade and a fence line soaker were added within the last ten years to the maternity building, in an effort to reduce heat stress. During the hot summer months, close-up cows favored lying on the concrete, even in excess moisture from the feed line sprinkler system, rather than the bedded pack area. This caused an increase in mastitis after calving resulting in an increase in culling. Therefore, the K-State Dairy unit began to focus on further reducing heat stress in the close-up pen.

The dimensions of the maternity barn are 36 ft wide, 108 ft long and 9 to 10 ft high. The height of the bottom of the rafters hindered fan installation due to the type of equipment used to remove bedding. Another problem was the possibility of the cows reaching the fans. Natural ventilation was poor due to the sidewall height, solid sidewalls and lack of a ridge row opening. The building was enclosed on three sides and open to the south. The roof of the building is insulated. The north wall contained nine passage doors which remained open during warm weather. The Dutch doors allowed the top to be opened while the bottom remained closed in cooler weather. Originally, each door provided access to individual calving pens which had been removed.

The K-State Dairy team explored options to reduced heat stress in the maternity pen in addition to the feedline soakers. One goal was to create an environment which encouraged cows to lie in different parts of the pen. This was accomplished by distributing fans along the north wall. Also, an evaporative pad was installed to cool the air being blow into the bedded pack area of the maternity pen.

The evaporative pad, 4 ft by 80 ft, was installed north of the existing wall (Figure 1). The enclosed air chamber space between the pad and building was 6 ft. Eight 36 inch, ½ hp fans were installed in existing north wall. A fan was placed in the upper half of each door resulting in a fan spacing of 12 ft on center. Fans were mounted approximately 4 ft above the floor, to minimize blowing the bedding and potentially increasing respiratory problems due to suspended dust particles.

Figure 1 Cross section of air chamber and evaporative pad installed on north side of the KSU Maternity building.



Evaporative cooling is the result of warm air coming in contact with a stream of moisture or a wetted surface. The air temperature decreases and the humidity level increases as moisture is added to the air. Theoretically, the lowest air temperature obtainable occurs at 100 % humidity or saturation. Most designers assume the air temperature exiting an evaporative pad is reached when the air has absorbed 75 % of the moisture possible between inlet conditions and saturation. The temperature drop of the air across the evaporative pad is a function of the relative humidity. If two air streams are at the same temperature but have different relative humidity levels, the stream with the lower humidity will cool to a lower temperature than the air with higher humidity. The exhaust temperature from the pad also changes as the outdoor air temperature is changes.

Results

The temperature drop across the pad is shown in Figure 2 from August 1 to 15, 2007. During the first week in August the pads were off and there was no temperature difference between the ambient air and air inside in the air chamber (pad temperature in Figure 1).

Figures 3, 4 and 5 compare the temperature, relative humidity and temperature humidity index during a 24 hour period when the pad was either on or off. The pad was allowed to dry between 12:30 and 6:15 a.m. thus there were no temperature differences during this period. The evaporative pad cooled the air temperature between 10 and 15 ^{o}F in the afternoon. Since the air passing through the evaporative pad absorbed moisture, the relative humidity was increased in the afternoon when the pad was on (Figure 4). The increase in relative humidity was a function of ambient relative humidity. Figure 5 shows the temperature humidity index was reduced by 3 to 5 units when the pad was operating.

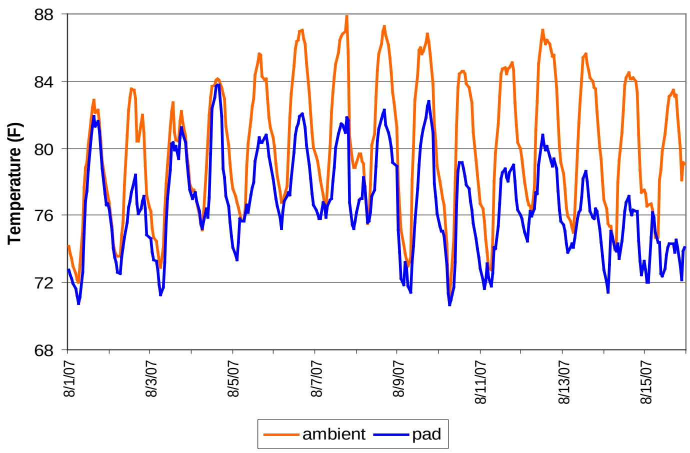


Figure 2 Ambient temperatures entering the evaporative pad and the exhaust temperatures of air entering the maternity bedded pack area.

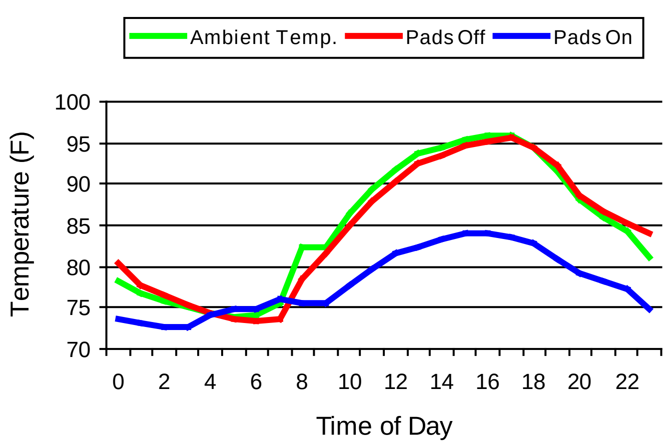


Figure 3 Impact of evaporative pad on air temperature during a 24 hour period

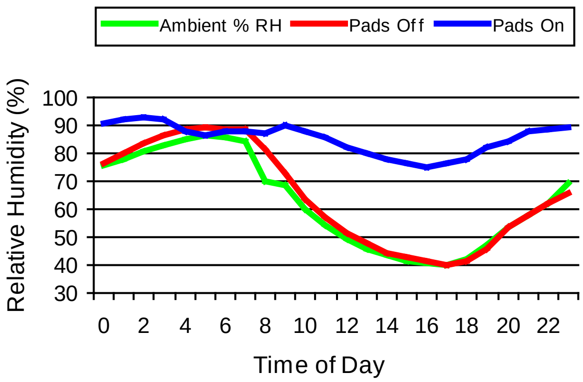


Figure 4 Impact of evaporative pad on air relative humidity during a 24 hour period

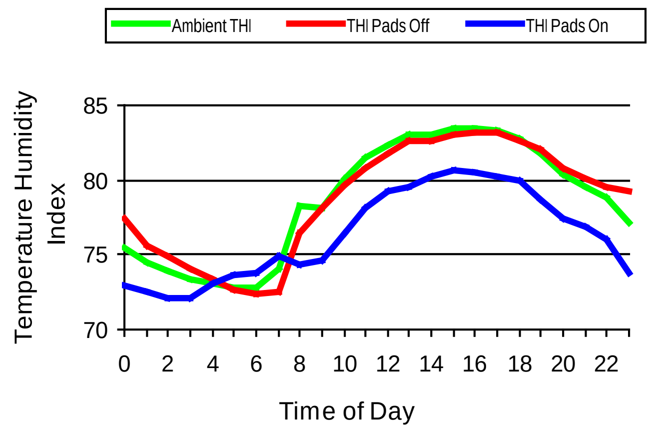


Figure 5 Impact of evaporative pad on air temperature humidity index during a 24 hour period

Differences in core body temperatures when the pad was on or off, are shown in Figure 6. Evaporative cooling lowered core body temperatures a 0.5 °F. During a 24 hour period, the duration of core body temperatures above 102 °F was 16 hours when the pad was off as compared to 6 hours when the pad was on.

Table 1 gives the water used from August 14-17, 2007. The air absorbed 101 to 112 gallons per hour on August 14, 15 and 17 when the relative humidity averaged less than 50 %. The temperature drop across the pad was approximately 14 °F. On August 16, the humidity averaged 65 % and water usage reduced to 65 gph and the average temperature drop was 9 °F. This illustrates the impact of the relative humidity on the cooling potential of the air. Approximately 0.33 gph per square foot of pad was utilized which is similar in other studies.

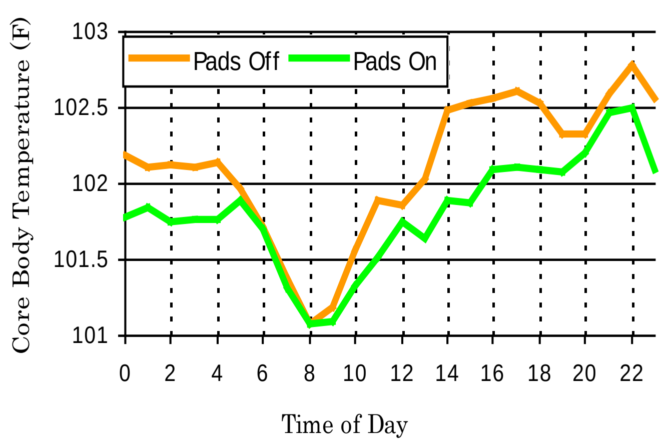


Figure 6 Impact of evaporative pad on core body temperature of close-up cows.

Table 1 Water performance of evaporative pad and water usage from August 14 to 17, 2007.

Date	Ambient		Evaporative Pad		Water Usage	
	Temp (^{o}F)	RH (%)	Temp (^{o}F)	RH (%)	gal/hr	gph/sq.ft.
Aug 14	91	43	77	82	101	0.32
Aug 15	91	41	76	83	110	0.34
Aug 16	86	65	77	92	65	0.20
Aug 17	94	43	78	90	112	0.35

Summary

An evaporative cooling system was installed in the KSU Dairy Maternity building. The cooling system reduced the air temperature in bedded pack area 10 to 15 ^{o}F during the afternoon hours. Relative humidity was increased to 70 to 80 %. However, the temperature humidity index was reduced 3 to 5 units. Cows were not observed lying on wet concrete as previously had been seen during summer heat. However, cows did appear to stand during the afternoon hours in front of the fans to take advantage of the cool air being blown into the bedded pack area.

Evaporative cooling may provide an alternative to dairies with facilities where side wall heights limit installation of fans. An advantage of the evaporative cooling system is that no additional water is added to the lagoon. A fence line soaker system may still be necessary to encourage cows to eat and provide additional cooling.

Acknowledgements

Special thanks to the employees of the K-State Dairy unit who provide assistance during installation of the evaporative cooling system and experiments. Also, thanks to Rick Zimmerman of Aerotech Manufacturing for his assistance in securing the necessary equipment and the Western Dairy Management group for their financial support.

Influence of Facilities on Cow's Time Budget

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Introduction

The daily activities of a dairy cow typically consist of feeding, resting, drinking, socializing and milking. Research indicates that, except for milking, a cow budgets, or sets aside, a certain amount of time for each of these daily tasks. Some milking procedures and parlor characteristics influence how much time a cow spends away from the housing area, though. These factors include the amount of time spent in the parlor, travel distance to and from the parlor, group size, milking routine and visits from the veterinarian. Each of these variables affect the amount of time left for a cow's other important daily activities.

Facilities are another critical factor in a cow's daily use of time. In many cases, freestall dairy facilities are often overstocked to reduce the facility investment cost per cow or to allow gradual expansion of the dairy herd. Unfortunately, overstocking freestalls and feed spaces reduces the time available for cows to meet their individual time budgets. This publication investigates the degree to which the facilities and the actual time spent at the milking center impact a cow's use of time on a daily basis.

Past Research and Results

Research from different experts reveals a direct relationship between a cow's daily amount of resting time and the amount of milk produced. Albright (1993) evaluated the time budget of a cow producing over 18,000 kg (40,000 lbs) of milk. He found she spent 13.9 hours per day resting and 6.3 hours per day eating. Matze's study (2003) discovered that cows in the top 10 % of milk production rested 14.1 hours per day, while average milk producers rested 11.8 hours per day. Both groups spent 5.5 hours per day eating, but the top 10 % spent less time perching, standing in alleys and drinking than the other group. Grant (1999) suggested daily time budgets for dairy cows should include 5 to 5.5 hours for eating, 12 to 14 hours for resting and 30 minutes for drinking. An additional study he conducted in 2006 indicated that each additional hour of rest results in a 1 kg (2.2) lb milk response.

Research also shows that the stocked capacity of a facility directly affects a cow's resting time and, therefore, milk production. Metz (1985) reported that when time is limited for normal cow behavior, cows prefer to rest rather than eat or drink. Batchelder (2000) found similar results when pens were overstocked at 130 %. He observed cows preferred to rest rather than eat immediately after milking because they had spent more time standing in alleys waiting for a stall. Grant (2006) reviewed available research and tentatively concluded that, though eating time is not greatly affected by stocking density, resting time is reduced 12 to 27 % when pens are stocked at 120 % or greater. He also concluded that standing time increases 15 to 25 % when stocking density exceeds 120 %. His final analysis was that, in general, there is a negative impact when stocking density exceeds 120 %.

Overton et al. (2003) compared commonly used methods such as the cow comfort index, stall use index and proportion lying index to evaluate dairy cattle resting behavior. The cow comfort index is the number of cows lying in a stall divided by the total number of cows lying and standing in a stall. The stall use index is defined as the number of cows lying divided by the total number of cows lying or standing but not eating. Proportion lying index is determined by the number of cows lying divided by the total number of cows in the pen. Overton concluded maximum stall usage occurred one hour after the cows returned from the early morning milking.

Facility Occupancy Index

The facility occupancy index is used to determine the impact of facilities on cow behavior. Before using a simple equation to calculate the occupancy index, though, the feedline occupancy rate and the freestall occupancy rate must also be known.

The feedline occupancy rate represents the average percentage of feeding spaces that are occupied while the cows are in the pen. The pen time (P_t) in the following equation excludes the time cows are traveling to and from the milk parlor or at the milk center. The feedline occupancy rate equals:

$$FEED_{OR} = \{(C \times F_t) / (F_s \times P_t)\} \times 100 \qquad (1)$$

$FEED_{OR}$ is the average feedline occupancy per day (%)
C is the number of cows in the pen
F_t is the desired daily feeding time per cow (hrs)
F_s is the number of 24 inch feed spaces available
P_t is the time per day the cows are in the pen (hrs)

The freestall occupancy rate represents the percentage of freestalls that are occupied while the cows are in a pen. Since proper usage of a freestall involves resting, this index is based strictly on cows resting or lying in stalls without considering cows perching or standing in stalls. The freestall occupancy index, or cow comfort index, is considered a reliable tool for evaluating stall usage. The following equation calculates the freestall occupancy rate:

$$STALL_{OR} = \{(C \times R_t) / (S_t \times P_t)\} \times 100 \qquad (2)$$

$STALL_{OR}$ is the average freestall occupancy per day (%)
C is the number of cows in the pen
R_t is the desired daily resting time per cow (hrs)
S_t is the number of freestalls in the pen
P_t is the time per day the cows are in the pen (hrs)

The facility occupancy index is calculated by adding the feedline and freestall occupancy rates, as shown below.

$$F_{OR} = STALL_{OR} + FEED_{OR} \qquad (3)$$

F_{OR} is the facility occupancy rate (%).

Ideally, facilities should not hinder cows from having adequate time for feeding or resting. The facility occupancy index must be less than 100 % if cows are to exhibit natural behavior (other than eating or resting). An assumption in this model is that certain cows will use freestalls or feeding spaces even when most of the cows are involved in activities outside the housing area. Other key assumptions include: cows are healthy, stalls are bedded properly, and feed is readily available. The acceptable facility occupancy index must be less than 100 % when lame cows are standing in stalls, adequate fresh feed is not available, or minimum bedding is used.

If at least one stall and one feed space is available per cow and time away from the pen does not exceed 3 hours per day, then the facility occupancy index will be equal to or less than a beneficial 85 %. If the facility occupancy index is between 85 % and 100 %, the facilities may not hinder the cow's normal behavior, but the pen is overstocked. When the facility occupancy rate index exceeds 100 %, some cows may be limited from exhibiting normal behavior.

Dangers of Overcrowding

If 100 lactating cows are housed in a 67-stall pen, making the stocking density 150 %, then the facility occupancy index equals 132 %. When the cows are not at the milking center, 93% of the freestalls must be occupied to ensure adequate resting time for each cow in the pen. In addition, 39 % of the feeding spaces must be occupied. Once the facility occupancy index exceeds 100 %, cows must choose between feeding and resting, therefore preventing them from exhibiting normal behavior.

Table 1 illustrates the impact of overcrowding of dairy facilities at 0%, 25%, and 50%. Assuming the herd size is 100 cows, the results are related to the number of cows per stall and the amount of time spent per milking. Overcrowding by 25 % results in a facility occupancy index of 110 %, with 120 minutes per milking. If the time at the milking center is reduced to 60 minutes, then the facility occupancy index decreases to 100 %, since 2 additional hours are available each day in the housing area. Facilities that are overcrowded by 50% are still inadequate, even if time at the milking center is reduced.

Table 1: Facility occupancy rate based on a milking frequency of 2 times per day

Time at Milking Center (min/milking)	Overcrowding of Facilities (%)	Freestall Occupancy Rate (%)	Feed Line Occupancy Rate (%)	Facility Occupancy Rate (%)
120	0	62	26	88
120	25	78	32	110

120	50	93	39	132
60	25	70	30	100
60	50	84	36	120

Impact of Milking Time

Research suggests 20.5 hours in the housing area is the minimum time required for a cow to socialize, rest, drink and feed. Cows which are in the milking parlor more than 3.5 hours per day may not have adequate time for normal activities.

Table 2 uses data from a 100-cow dairy to illustrate the impact of milking times on facility occupancy rate, assuming there is no overstocking of the feedline or freestalls. Data was gathered from 2 times of milking per day with times at the milking center of 60, 120 or 180 minutes per milking.

Table 2: Facility occupancy rate based on time at milking center per milking

Time at Milking Center per Milking (min)	Travel Time to and from the parlor (min)	Freestall Occupancy Rate (%)	Feedline Occupancy Rate (%)	Facility Occupancy Rate (%)
60	10	56	23	79
120	10	62	26	88
180	10	69	29	98

Table 2 suggests these particular facilities are not a limiting factor to a cow's time budget because the facility occupancy rate is less than 100 %. If facilities are not overstocked, the freestalls will only be occupied 60 to 70 % of the time, even with longer milking times. It is important to remember that, on average, 56 % of the freestalls need to be occupied if the desired resting time is 12 hours per day, assuming time in the parlor is limited to 1 hour or less per milking.

To evaluate the impact of time at the milking center, cow time budgets for the first and last cows through the parlor were also examined. The model inputs include: time at the milking center, travel time to and from the milking center, time in the wash pen, and daily time allowance for veterinary activities. Time for the veterinarian is assumed to occur only once per day, while the other time allocations occur at each milking.

Using the 100-cow dairy example, Table 3 compares the time at the milking center to the resting time available for the first and last cows through the parlor. The facilities enable the first cows through the parlor to potentially rest for 15 hours per day, as compared to the intended 12 hours per day. The last cows through the parlor can obtain the targeted 12 hours of rest if the time at the milking center is limited to one hour or less. They do not receive adequate rest if they are at the milking center two or more hours per milking. Cows moving through the parlor during the first half of the milking shift have plenty of time for their normal daily activities.

Table 3: Time at the milking center compared to the resting time of cows milked first and last in the parlor

Time at Milking Center (min)	Travel Time (min)	First Cows Through Parlor (hrs)	Last Cows Through Parlor (hrs)
60 (2X Milking)	10	15	12.8
120 (2X Milking)	10	15	10.8
180 (2X Milking)	10	15	8.8

Table 4 illustrates the difference between 2 times and 3 times of milking per day. The first cows through the milking center are not necessarily impacted by milking frequency. However, the resting time of the last cows through the parlor is influenced by milking frequency, time at the milking center and overcrowding. When milking 3 times per day, the time at the milking center must be reduced to less than one hour each time. The last cows through the parlor will only have 8.5 hours of resting time with 2 hours of milking 3 times each day.

Table 4: Influence of milking frequency on facility occupancy rate and resting time

Time at Milking Center (min per milking)	Milking Frequency	Number of Stalls	Over crowding of Facilities (%)	Facility Occupancy Rate (%)	Available Resting Time (hrs)	
					First Cows Through Parlor	Last Cows Through Parlor

120	3X	100	0	100	13.1	8.5
120	3X	80	25	125	13.1	8.5
120	2X	100	0	80	13.9	10.8
120	2X	80	25	110	13.9	10.8
60	3X	100	0	85	14.1	11.5
60	3X	80	25	106	14.1	11.5
60	3X	100	0	85	14.6	12.8
60	2X	80	25	100	14.6	12.8

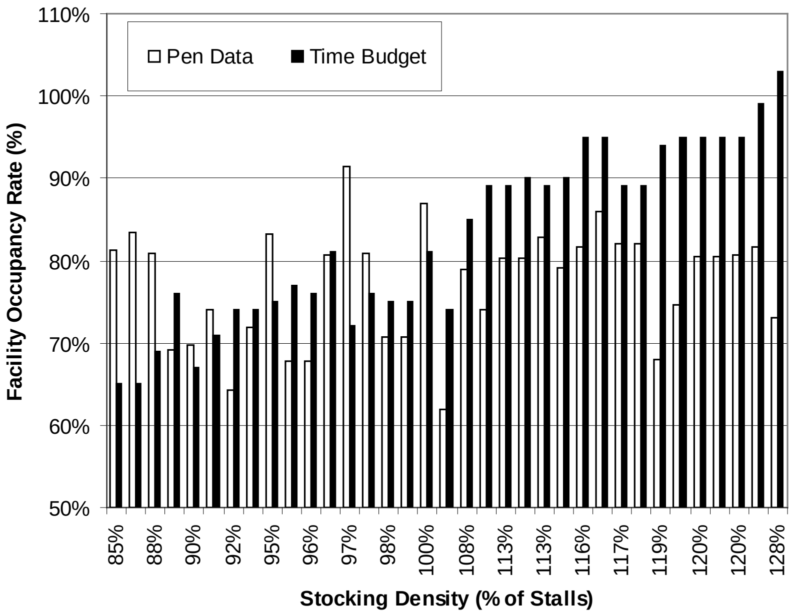
Kansas Dairy Research

A research study was conducted at Kansas State University in the fall of 2007 to evaluate the potential impact of facilities on dairy cows' feeding and resting time allocations. The impact of time away from the feeding and resting area was also evaluated.

A Kansas dairy with 7 pens of lactating cows was used for evaluation..There were two pens with 60 stalls, one pen with 88 stalls and four pens with 100 stalls. Hourly data was collected between 9 a.m. and 4 p.m. on five different days. The dairy limited pen stocking density to 85 to 125 % based on the number of free stalls available. Data collected from each pen included the number of cows lying in free stalls and the number of cows eating at the feedline. Information was only collected when all the cows assigned to a pen were present and not at the milk center.

.Only once were more than 85 percent of the cows found to be resting or feeding at any given time during the study. As the stocking density increased beyond 100 %, the FOR index predicted 90 to 100 % of the cows must be resting or feeding in order to obtain 12 hours of rest and 5 hours of feeding. Therefore, once the FOR index exceeds 85 percent, the cows' normal time budgets for resting, feeding, drinking and socializing may be altered. When the cows are at the milk parlor 3 hours per day, the remaining time in a housing area equals 21 hours per day. In addition, 3 hours, or 15 percent of the day, are required for socializing within the housing area, which explains why the facility occupancy rate should not exceed 85 percent. Additional studies at different facilities and various seasons are required to determine if facility occupancy rates are observed at other dairies.

Figure 1: Illustrates the impact of stocking density and the facility occupancy rate (FOR) for all data collected



Comparison to Other Research Study

Data was taken from Overton et al. (2003) to evaluate the concept of facility occupancy index and to use the data as model inputs in the Kansas study. The Overton study used 129 cows in a 144 stall pen with 144 feed spaces, and the cows spent 2 to 3 hours per day at the parlor. The feedline occupancy rate was 21 %, the freestall occupancy rate was 54 %, and the overall facility occupancy rate was 75 %. These results indicate the facility was not limiting cows from obtaining 12 to 13 hours of rest and 5 to 5.5 hours of feeding time.

Data gathered from the Overton study tracked the number of cows lying down during a 24 hour time period. Their results suggest the average number lying down was 50 to 54 %, with a range of 76 to 25 %, and the freestall occupancy rate was similar at 54 %. The research shows the facility occupancy index may provide a reasonable method to evaluate facilities without the use of videotaping or 24 hour visual observations.

Conclusion/Summary

As research of facility occupancy index continues, care must be taken not to misuse the results in the dairy industry. Additional stress on employees to increase milk parlor capacity so cows have more time in an overstocked pen is not the purpose of this tool. Knowing a facility's occupancy index may be useful in identifying behavior inhibitors to the animals, though. The

FOR helps explain why it is sometimes difficult to move animals to the pens or why there is agitation among some cattle pens.

The facility occupancy index provides a management tool to evaluate the impact of facilities on cow time budgets. Research suggests when facilities are overcrowded by 25 % or more, they begin to limit cows from exhibiting normal behavior. The feed, freestall and facility occupancy indices are based on the percentage of cows that must be resting and feeding during a given time in a pen. Overcrowding results in inadequate time for typical resting and feeding activities. Using the FOR index provides a way to determine if the particular facilities will allow cows to exhibit normal behavior in a pen without practitioners having to analyze videotape or conduct 24 hour visual observations.

The model also may be used to evaluate the impact of time at the milking center and milking frequency on the cow's time budget. A study of different scenarios indicates the first cows through the parlor have adequate time for resting, feeding, socializing and watering. However, the last cows have inadequate time for other activities if they spend 2 or more hours per milking at the milking center. Reducing time at the milking center is critical when milking 3 times per day in order to ensure the last cows have adequate time for normal behavior activities when in the housing area.

Considerations for Optimum Milk Production and Happy Cows:

- Resting time should be 12 or more hours per day.
- Eating time should be approximately 5 hours per day.
- Drinking time should be approximately 30 minutes per day.
- Time for socializing should be around 3 hours per day.
- Time in the milk parlor should be 75 minutes or less for each milking session if milking twice each day.
- Time in the milk parlor should be 45 minutes or less each time if milking three times each day.
- Stall usage should be 60-70%.
- Avoid overstocking the facility at greater than 15%.

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Water Requirements for Lactating Cows During Summer Months

M.J. Brouk, J.P. Harner and John F. Smith

Introduction

Minimum water requirements for meeting the intake water needs of lactating cows, milk parlor usage and other needs of a functioning dairy seem to range from 40 to 50 gallons per cow per day (gal/cow/dy) (Allen el al., 1974; Bailey et al., 1993; Beede, 1992; MWPS-7, 1997). Lactating milk cows will drink from 30 to 50 gallons of water per day. Ishler (1998) notes drinking water satisfies 80 to 90 percent of the daily water requirements of a dairy cow. A summary of daily water requires for different type of dairy cattle is shown in Table 1.

Reinemann and Springman (1992) determine the drinking water requirements based on 4.5 to 5 lbs of water per lb of milk. Data collected during a study comparing the impact of fiber by Dado and Allen (1995) indicates a cow will drink about 1.5 gal of water per trip to a watering trough at a rate 1.3 gpm. They found a cow will spend about 12 to 16 minutes per day drinking water (Dado and Allen, 1995). Their measured free water intakes were lower than most studies.

Anderrson et al (1994) in Sweden studied the impact of flow rate on water intake using cups. The flow rates examined were 0.5, 1.8 and 3.2 gpm. Time spent drinking decreased from 37 to 11 to 7 minutes per day as the flow rate increased. They observed drank from the cups 40, 28 and 30 times per day. The actual water drank increased from 20.4 to 22.0 to 23.3 gal/dy/lcow as the flow rate increased, however, there was not increase in milk yield or dry matter intake. Submissive cows drank 7% less water than a dominant cow. In another European study, water troughs were compared to water cups (Castle and Thomas, 1975). Cows spent only 2 min/dy drinking from water troughs while the were at water cups 7.8 min./dy. Drinking rate range from 1.2 to 6.5 gpm/cow with lower rate being consumed from the water cups.

Table 2 summarizes the daily water usage on the five dairies in Arizona (Zuagg, 1989). Early lactating cows drank between 29 and 35 gal/dy/cow while later lactating cows utilized only 25 to 30 gal/dy/cow. This is a function of milk production and feed intake. Water consumption was reduced below 20 gal//dy/cow during the dry cow period on all of the farms. Water usage on a dairy varied from 80 to 240 gallons per lactating cow per day (gal/lcow/dy). Dairies raising replacement heifers and using calf barns utilized more than 200 gal/lcow/dy.

Zuagg (1989) also indicated the Arizona Department of Water Resources was adopting 105 gal/lcow/dy and 20 gal/nonlactating cow/dy as the maximum water usages for dairies by the end of 2000. In South Florida, dairies apply for a consumptive use permit use 40 gal/cow/dy for drinking and 130 gal/cow/dy for flush water (Bray et. al., 1994).

Other studies have looked at the impact of water temperature on water consumption. Beede (1992) summary indicate cows per warm water to cool water. Bray et al. (1990) studied the impact of water from a well (77 ^{o}F) to chilled water (59 ^{o}F). They found no difference in milk yield (61.4 to 61.8 lbs/d/lcow). Similar results were found the following year (Bray et al. 1991).

Some data indicates that cows prefer the water temperature to be near 80 ^{o}F (Beede, 1992).

The objective of this study was to determine water usage during periods of heat stress and the impact of water trough location in a freestall.

Study Procedures

Three dairies were selected in north central Kansas for the study during the summer 2000. Figure 1 shows the layout water troughs in the 4-row freestall building. Fans and a feedline sprinkler system were used for heat abatement. Holstein cows were milked 2X with a rolling herd average of 72 lbs per day. Each pen contained 84 freestalls with a stocking density of 110 percent. Water meters recorded water consumption at each water trough from July 1 to September 15, 2000. Meters were read approximately every two weeks. The water usage data included the amount of water used to refill the water troughs after dumping. The troughs were dumped twice a daily as the cows were being milked. Walking distance from the back of the milk parlor to the housing area was less than 100 feet.

Figure 2 shows the water trough location in the 2-row freestall facility. Similar procedures to those previously mentioned were utilized. The milk parlor was a double 12 parlor with two exiting lanes. Water troughs were located near the end of the exit lane and were equipped with water meters. Cows had to walk 400 to 500 feet from the milk parlor the freestall buildings. Each freestall had 108 freestalls and was stocked at 100 percent capacity. This herd was milked 3X with a rolling herd average of 78 lbs/dy/cow.

The third dairy selected was a 4-row freestall housing Jerseys with a rolling herd average of 65 lbs milk per day. Building layout was similar to Figure 1 except the pens housed cows in different stages of lactation. The walking distance from the milk parlor to the freestall housing area was 30 feet. The herd milk production was 65 lbs/dy/cow.

Water temperature was not recorded during the study period. The water was supplied from deep wells. Each water trough was connected to the main distribution line using a ¾ inch hose.

Drinking Water Requirements

Figure 3 shows the average daily water usage per cow collected during summer, 2000 in the 4-row freestall building. The average water consumption was 35.1 gal/cow/dy including the water used to refill the tanks after dipping. Figure 4 shows the water consumption at the different troughs in each of the pens. Over 40% of the water was consumed from the water trough located in the center cross alley (Figure 5). The water trough located farthest from the travel lane to the milk parlor had lower usage. However, the 3 to 5 percent differences may be attributed to lack of water trough at the exit lanes from the milk parlor. The water trough nearest the travel lane is less than 100 ft from the milk parlor.

Figure 6 shows the daily water usage for the 2-row freestall buildings. Data from the north pen more accurately reflects the water consumption of this herd at 40.2 gal/dy/cow plus an additional 3.5 gal/cow/day at the milk parlor water tank. Data from the south pen shows the impact of a leaking water line (Figure 7). Average water usage per cow increased from 40.2 to 58.9 gal/dy/cow. This represented nearly a 50 percent increase in water consumption during the study period. Figure 7 shows the water usage at the individual water troughs in the north and south buildings. The water meter reveals the impact of the leaking water line at the water trough farthest from the travel lane in the south building. Water usage at the center water trough and water trough near the travel lane were similar.

Figure 8 shows the water usage at the water troughs located in the milk parlor exit lanes. There was no difference between the usages of water in the west or east exit parlor lane. The total water usage at the exit lane was approximately 3.5 gal/dy/cow or about 3.5 gal/day or about 8% of their daily consumption.

The third site found Jersey cows required significantly less water. Data collected during summer, 2000 found late lactation cows, early lactation cows and 2-year old heifers drank 20, 24.5, and 21.4 gal/dy/cow.

Summary

The farms with Holstein cows used 4 to 4.5 lbs of water per lb of milk produced. The Jersey cows used 3.1 lbs of water per lb of milk production with the water trough. The data from this study compares with data presented by McFarland (1998). He reported 35 to 45 percent of the water consumed was from a water station in the central crossover. The data shows the importance maintenance may have on reducing water usage on a dairy. Water usage in freestalls for drinking increased as milk production increase. Adequate water rights are needed to make allowances for future increases in milk production.

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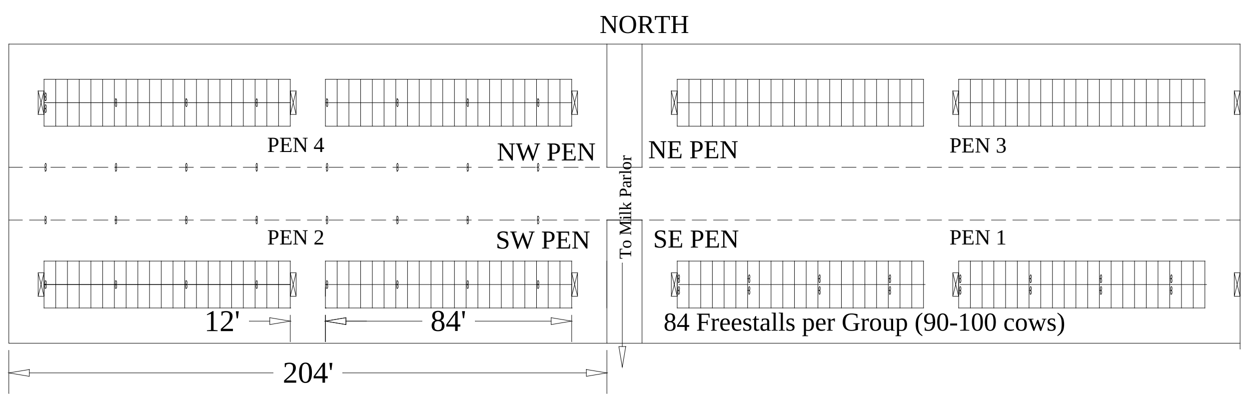

Figure 1. Layout of pens and location of water troughs in 4-row freestall building.

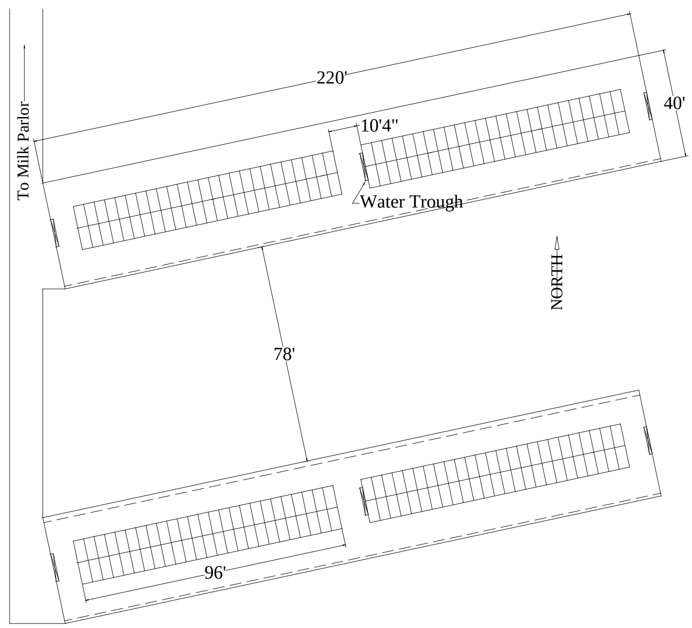

Figure 2. Layout of 2-row freestall buildings and location of water troughs.

Table 1. Estimate of drinking water requirements for different dairy animal types (MWPS, 1999).

Animal Type	Water Usage (gallon/day/head)
Calves (1 to 1.5 gal/100 lbs)	6 to 10
Heifers	10 to 15
Dry Cows	20 to 30
Lactating Cows	25 to 50

Table 2. Summary of daily water usage on five dairies in southwestern United States (Zaugg, 1989).

	Dairy Identification and Milking				
	A(3X)	B(3X)	C(2X)	D(2X)	E(3X)
Daily Water Usage					
Total Gallons per Lactating Cow*	186	101	95	72	182
Drinking					
Early Lactation	34	31	30	29	35
Late Lactation	27	28			25
Dry Cow	16	13			17
Close-up		16			17
Calves (hutches or barns)		3	2	2	25**
2-6 months		3	4	4	5
7-15 months					10
16-22 months					11

* Total water usage divided by the number of lactating cows.
** Includes cleaning and sanitizing wire cages, concrete floors and alleys.

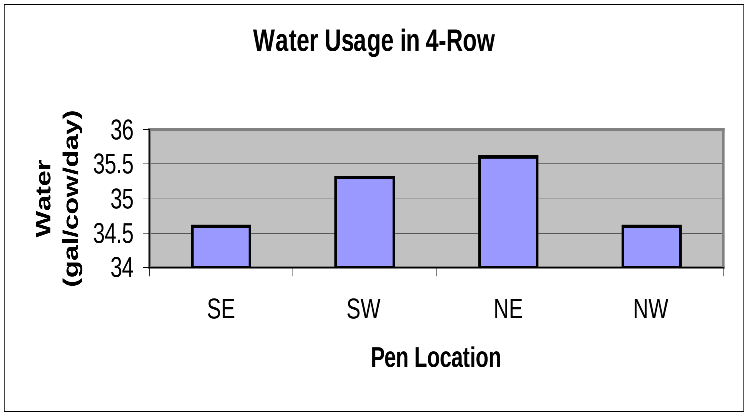

Figure 3. Total daily water (gal/dy/cow) used at water troughs in different pens in 4-row freestall building.

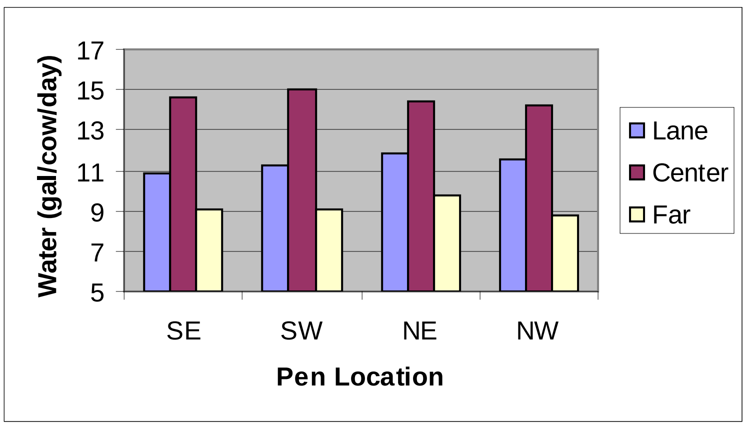

Figure 4.

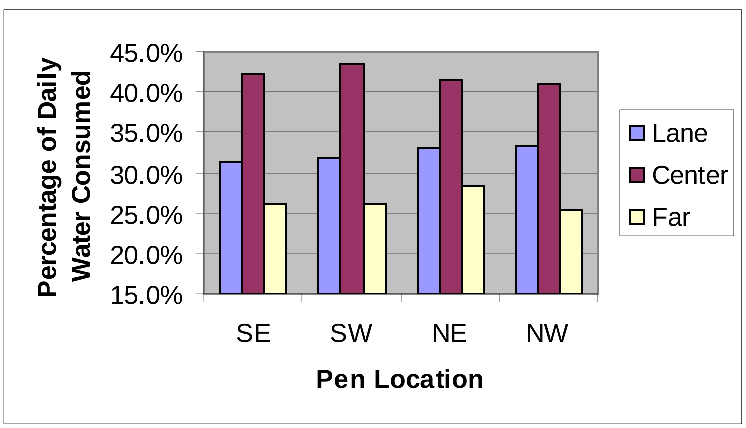

Figure 5. . Water used (gal/dy/cow) at water troughs located in different selections of a 4-row freestall building.

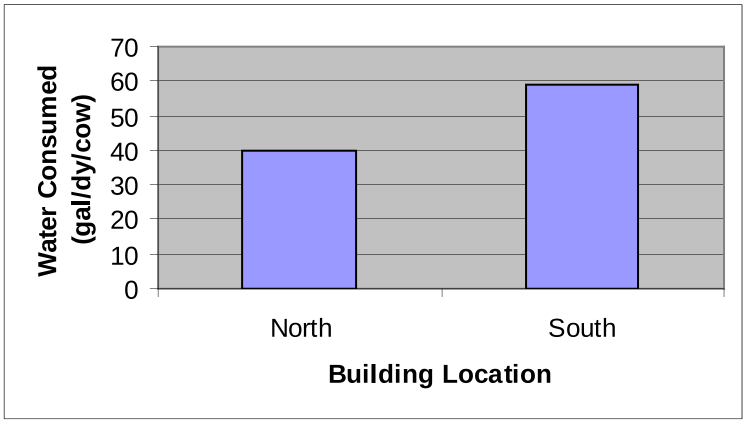

Figure 6. Total daily water (gal/dy/cow) used in 2-row freestall building.

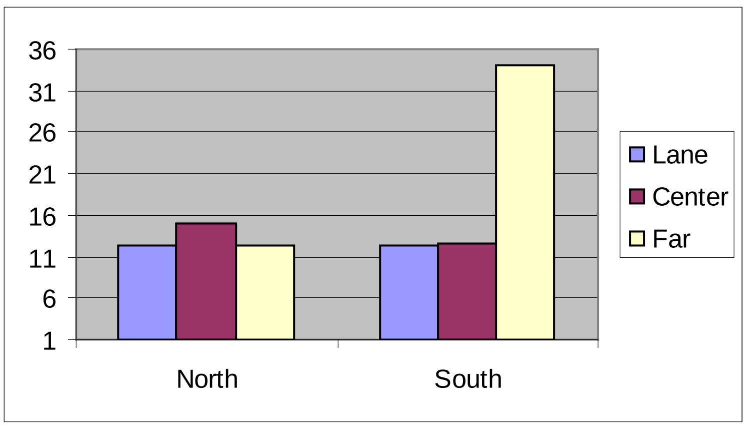

Figure 7. Water used (gal/dy/cow) at water troughs located in different selections of a 2-row freestall building.

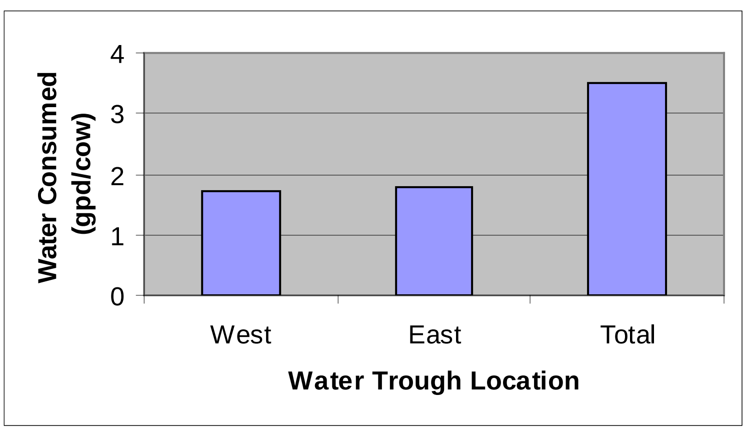

Figure 8. Water used at water troughs located at milk parlor exit lanes.