Design Considerations for Low Profile Cross Ventilated Freestall Facilities

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TAKE HOME MESSAGES

- Width of low profile buildings vary; from 200 to 500 feet. There is approximately a 1^{o} F temperature rise across the building per 100 feet of building width.
- The average building temperature is 20^{o} F warmer than the ambient temperatures during the winter months. .Winter ventilation rates influence the temperature increase.
- Placement (number) of doors in the end walls is personal preference. Fewer doors results in more interior space allocated for vehicle maneuverability.
- The milk center may be naturally, tunnel or cross ventilated on dairies with low profile cross ventilated housing areas.

INTRODUCTION

The MCC dairy group in South Dakota began operation of the first completely low profile cross ventilated building in the fall of 2005. Prior to construction of an 8-row building, this group had constructed a new, basic 4-row facility with cross ventilation. Since that time LPCV facilities have grown in popularity until, currently, there are LPCV buildings under construction or operating in seven states and being considered in 10 more states. The concept of LPCV has been extended from 8 to 24-row buildings across North America, but buildings with 12 and 16 rows of freestalls are the most common.

Advantages of LPCV facilities include a lower roof line, a smaller building footprint, shorter walking distance to and from the parlor, controlled lighting, and environmental control. As more buildings are constructed, design considerations and solutions are implemented, but this paper outlines areas where optimal solutions have not yet been identified in LPCV buildings.

In the spring and summer of 2006, the first data was collected on a low profile cross ventilated dairy facility in Milnor, ND. Information concerning ventilation, air quality, lighting, noise, dust and vaginal temperatures of the cows were collected at the North Dakota site. Temperature and humidity data were collected at four additional sites in the summer of 2007, and two sites during the winter of 2008. Facilities monitored after 2006 were 400-feet and wider. All of the data presented in these proceedings was gathered from facilities that used evaporative pads to provide the evaporative cooling.

BUILDING: WIDTH

The air exchange rate is an important consideration with LPCV buildings. An air exchange is equivalent to replacing all of the air inside the building with fresh air. During warm weather, the targeted air exchange rate is 60-120 seconds, which means that the fans move enough air to completely exchange indoor air with outdoor air every 60 seconds.

Building width plays an important role in the air exchange rate. Building widths of LPCV facilities are usually either 200 feet (8-row), 250 feet (10-row), 300 feet (12-row), 400 feet (16-row), or 500 feet (24-row).

Table 1 shows the air exchange time based on different velocities and a 10 foot air inlet for each foot of building length. Manufacturers recommend a maximum velocity of 400 feet per minute (fpm) through an evaporative pad because higher velocities result in decreased pad efficiency. Higher inlet velocities are possible, however, with a high-pressure mist system. Buildings wider than 300 feet have exchange rates of 109-231 seconds, depending on the crucial inlet velocity.

Table 1: Comparison of Building Width and Air Velocity on the Air Exchange Rate (seconds per exchange)

Air Velocity Through the Air Inlet (cfm/sq. ft.)	**Nominal Building Width (14 ft eave height & 0.5/12 roof slope)**				
	200 (3,200)*	250 (3,500)	300 (4,200)	400 (5,600)	500 (9,600)
250	77	100	123	174	231
300	64	83	103	145	192
350	55	71	88	125	165
400	48	62	77	109	144

* Approximate cross-sectional area of the building (cubic feet).

VENTILATION: BAFFLES

The interior of an LPCV building is very similar to a naturally ventilated freestall. However, one exception is the addition of baffles in an LPCV building to divert air from the head space back into the stall area. Baffles increase air speed in the stall area from 2-3 miles per hour (mph) to 6-8 mph, depending on the number of baffles. The first several LPCV buildings were constructed with baffles, but there has been a recent trend toward eliminating them to reduce cost and baffle damage by equipment. Baffles are sometimes damaged by skid steer equipment used to scrape manure. As a result, some dairies opt to use a heavy canvas material to create flexible baffles in crossover and transfer lanes. Baffles constructed from canvas are more forgiving of operator error and less likely to be damaged.

The bottom of the baffle should be installed at least 7 feet from the floor to avoid cow and equipment contact. Economically, obtaining a breeze greater than 5 mph in an LPCV building is impractical without baffles because twice as many fans are required, resulting in higher summertime operating costs. The initial and continual operating cost of the additional fans must be compared against the baffles cost. Baffles should have minimal long-term operating or variable cost.

Initially, one particular dairy chose not to install baffles but later changed the design. With the addition of baffles, they observed better lay-down rates of cows between head-to-head rows of freestalls and, therefore, an increase in milk production.

HEAT STRESS RESEARCH

Data loggers were used to evaluate how an LPCV system reduces heat stress under different environmental conditions. Five different buildings were monitored during the summer of 2007. Each building had an evaporative pad cooling system and baffles. Three data loggers were mounted just below each baffle, and temperature and humidity were recorded every 15 minutes. The data was averaged by the hour and baffle location from July 17 to August 16, 2007, in order to determine the temperature rise across these structures. Figure 1 shows the hourly average temperature at different locations in a 500-foot wide LPCV building in Minnesota.

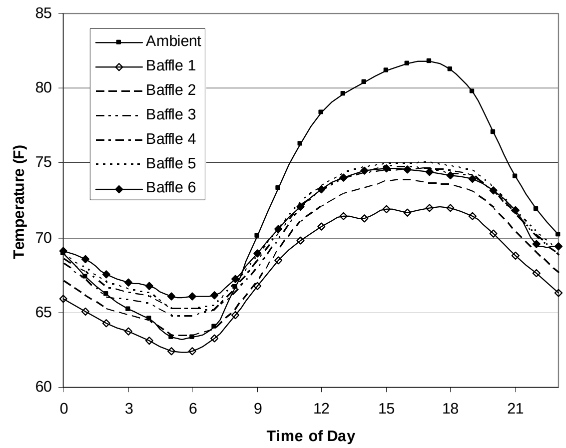

Figure 1: Average Temperature at Different Baffles in an LPCV Building from July 17 to August 16, 2007

Figure 2 plots the average hourly temperature humidity index (THI) inside the MN low profile building during the summer 2007. At the first baffle, the THI was 71 or below during the heat of the day. The THI ranged from 72 to 74 between noon and 11:00 p.m. at the last baffle in a wider LPCV building. This increase in THI is due to cow body heat increasing the temperature as the air moves across the building.

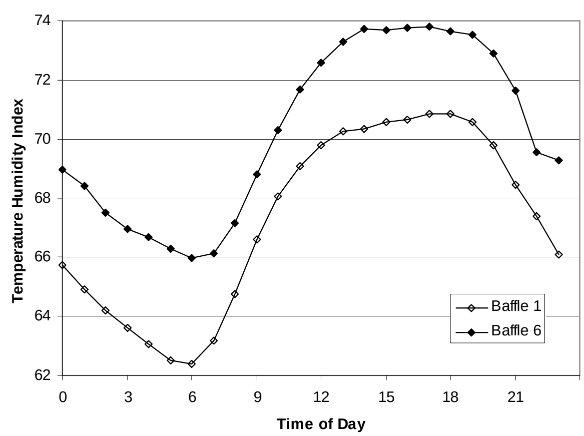

Figure 2: THI at the First and Last Baffle in an LPCV Building During the Summer of 2007

Figure 3 shows the average temperature from July 17 to August 16, 2007, at an LPCV dairy in Iowa. The average ambient relative humidity was 76.7% and ranged from 60 to 90%. During the afternoon hours the relative humidity dropped below 65%, but the cooling potential remained limited. The maximum cooling potential is only 10.5^{o} F if ambient conditions are 86^{o} F and 62% humidity. The average temperature drop across the evaporative cooling system was approximately 8-10^{o} F

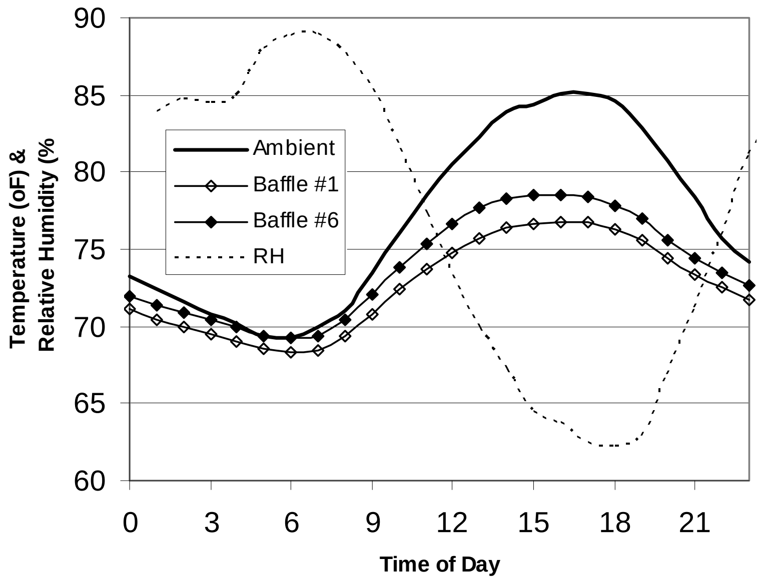

Figure 3: Average Ambient Temperature, Relative Humidity and Temperatures at the First and Last Baffles in an LPCV Building During the Summer of 2007

Table 2 is a summary of the temperature rise across LPCV buildings from July 17 to August 16, 2007. The data indicates that the average temperature rise between baffles is 0.58 ^{o}F, and the average temperature rise across the buildings is 0.0092 ^{o}F per foot of building width. Approximately 1^{o} F exists per 100 feet of building width. Since the building humidity is high due to the evaporative cooling system, there is also a 1-unit increase in the THI per 100 feet of building width.

Table 2: Average Temperature Rise Between Baffles and Per Foot of Building Width in 4 LPCV Buildings

Dairy ID	**Average Temperature Rise (^{o}F) Between Baffles***	**Average Temperature (^{o}F) Rise/Foot of Building Width***
# 1	0.65 ^{o}F	0.0085 ^{o}F/ft
# 2	0.51 ^{o}F	0.0077 ^{o}F/ft
# 3	0.62 ^{o}F	0.0110 ^{o}F/ft
# 4	0.47 ^{o}F	0.0095 ^{o}F/ft
Average	0.58 ^{o}F	0.0092 ^{o}F/ft

*Average values per dairy are based on 2,880 hourly average measurements, including nighttime data

Figure 4 shows the impact of THI based on the work of Berry et al (1964). The 70, 80 and 90 lb/day milk production curves in Figure 4 are derived from the equation also developed by Barry et al (1964). Their work looked at data from heat stress research conducted in the 1950's and 60's with cows milking 30-60 lbs/day. Increasing the THI from 75 to 79 results in a 4 lb/day milk production loss for a cow milking 60 lbs/day, which causes a 7% decrease in milk production. The data modeled for cows at 70 lbs and above shows even greater declines in milk production.

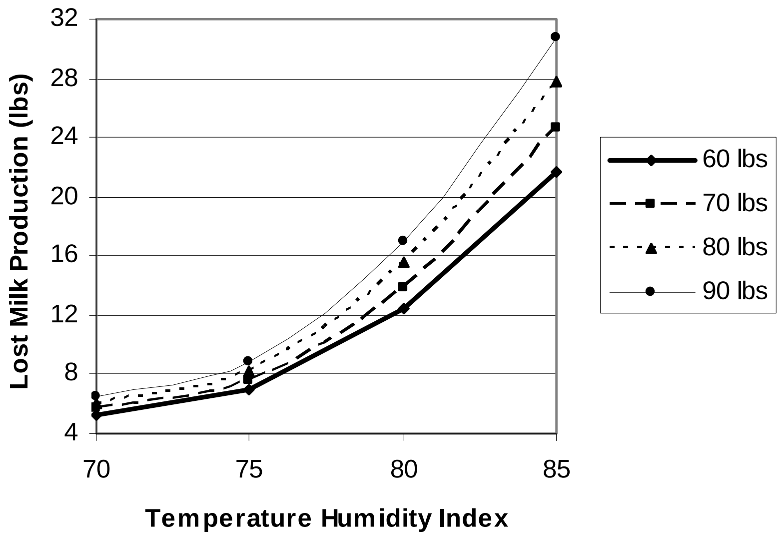

Figure 4: THI and Milk Production Loss for Cows Milking 70, 80 and 90 lbs (based on the equation by Berry et al (1964))

WINTER VENTILATION

Guidelines are relatively unknown for operating fans during the winter, and, currently, each dairy appears to have different operational modes. However, two main operational modes have emerged as most popular. The first mode decreases the air exchange rate by turning off the fans to prevent manure from freezing on the alleys. This strategy prevents potential cattle lameness but leads to increased ammonia levels inside the building. In addition, an increase in condensation moisture caused by interior and exterior temperature differences can develop. Moisture condensation is a result of warm, moist air contacting a cold surface. Moisture usually condenses on non-insulated metal surfaces, such as a purlin or the roof.

The second mode of action uses a controller to operate temperature-based fans along the inlet side of the building. This mode typically utilizes a minimum number of fans that operate below a minimal set point temperature. As outdoor air temperature decreases, the same amount of fans are still in operation, resulting in a colder temperature inside the building and potential frozen manure problems. Employees are also exposed to very cold temperatures at a minimal air speed.

Despite differences, some agreement exists that an 8-minute air exchange is the recommended maximum air exchange rate. Under the same winter conditions, a 16-row facility requires twice as many operating fans as an 8-row facility. Additional winter ventilation requirements in a 16-row facility mean the sidewall inlet opening must be double in size in order to exchange twice the volume of air as an 8-row building. However, mixing larger volumes of cold air with warm air often results in the first 200 feet of building being colder since more cold air must be pulled through the inlets to obtain the 8-minute air exchange rate. If the air exchange rate is equal, the air does not warm up as rapidly in a 16-row facility as compared to an 8-row facility during the winter months. In addition, during extremely cold weather, manure freezes quickly on the alleys closest to the air inlet in a 16-row LPCV building.

Management of winter inlets during snowfall is another important consideration because pulling air through an open inlet results in significant snow accumulation in the first cow pen. As a solution, the air could be pulled through the evaporative pad to prevent snow from entering the barn, but care should be taken that the pad does not become clogged with snow. This strategy may also reduce pad life.

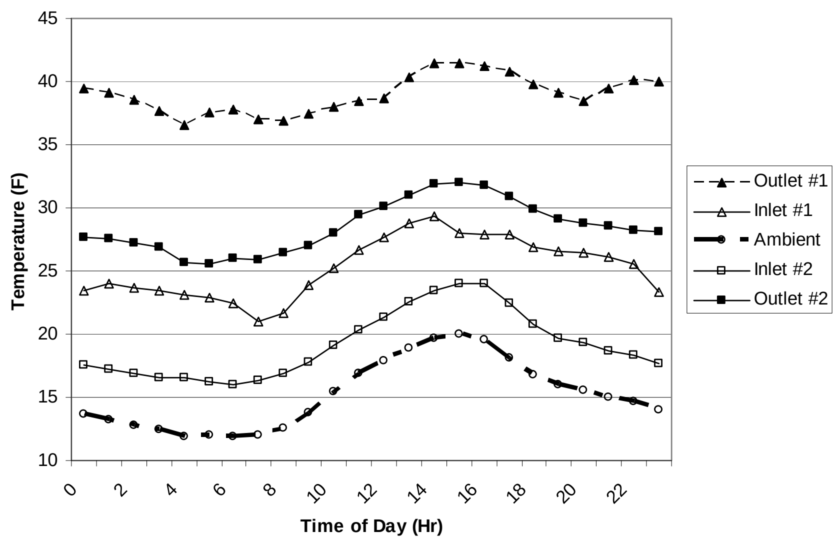

Figure 5: Summaries of Temperatures From Jan.18 to Feb.17, 2008, for 2 400-ft wide LPCV Buildings in Iowa

Proper winter inlet and curtain design is critical to provide the flexibility needed for winter time management. The winter inlet should be near the top of the sidewall to allow cold air to warm prior to contacting the cows or alleys. Another option is to use a split curtain to cover the pad. Typically, the curtains are split horizontally with the top curtain rolling upward and the lower curtain rolling downward, creating an inlet in the middle of the pad. The top curtain also may be automated to increase inlet opening as static pressure increases. If a single curtain is used, then the curtain should roll down from the top, allowing the air inlet to be near the top of a pad, or an 18-24 inch wide inlet should be installed above the curtain. Placing the inlet at the bottom of the pad allows cold air to immediately contact cows and alleys and decreases cow comfort and performance.

Temperature data was logged during the winter of 2008 at an LPCV facility in Iowa. The data was averaged by hour and baffle location from January 18 to February 17, 2008. As Figure 5 shows, the ambient temperature during the winter period averaged 20 ^{o}F colder than barn conditions. Figure 5 also shows a rapid warming of the air between the inlet and first baffle in two of the LPCV facilities. The air continued to warm until it was exhausted from the building. Figure 6 shows the exhaust air temperature as a function of the inlet (outdoor) air temperature. As the outdoor air temperature decreases, the variability in exhaust temperature increases. The exhaust air temperature is 25-45^o F when the inlet air temperature is -5^o F. The variability in data is due to a difference in air exchange rates since air temperature is lower at the exhaust as the air exchange rate increases.

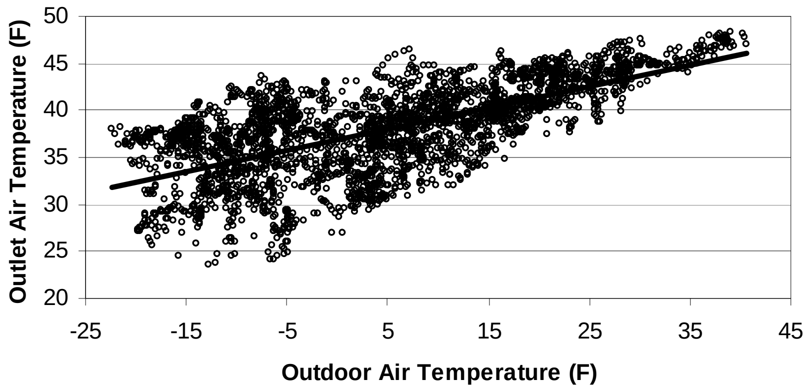

Figure 6: Outdoor Air Temperatures and Outlet Air Temperatures in an LPCV Building During the Winter of 2008

Figure 7 illustrates a correlation between temperature rise across the building and the outdoor air temperature. Temperature rise is defined as the difference between the exhaust and outdoor air temperature. Less variability exists in temperature rises above
20 ^{o}F since there are more consistent strategies in fan operation and less concern about freezing alleys.

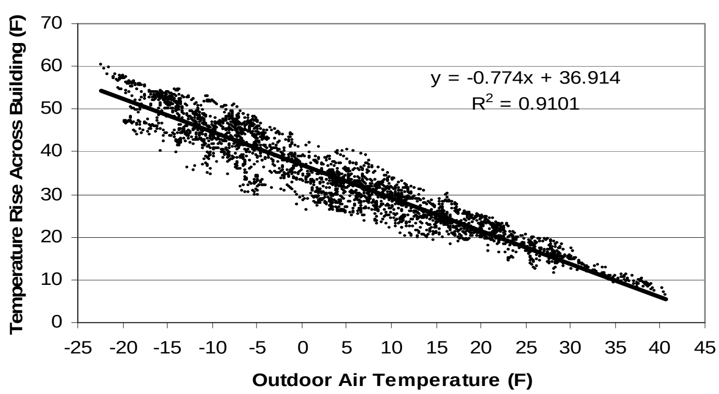

Figure 7: Outdoor Air Temperature and Temperature Rise Across a 500-foot wide LPCV Building in Minnesota During the Winter of 2008

Figure 8 shows the temperature rise from the first to last baffle during the winter of 2008 in two LPCV buildings. Since the buildings are under the same management, the lower temperature rise across LPCV #2 may be due to a lower stocking density or the fact that dry cows and heifers are housed in that particular building

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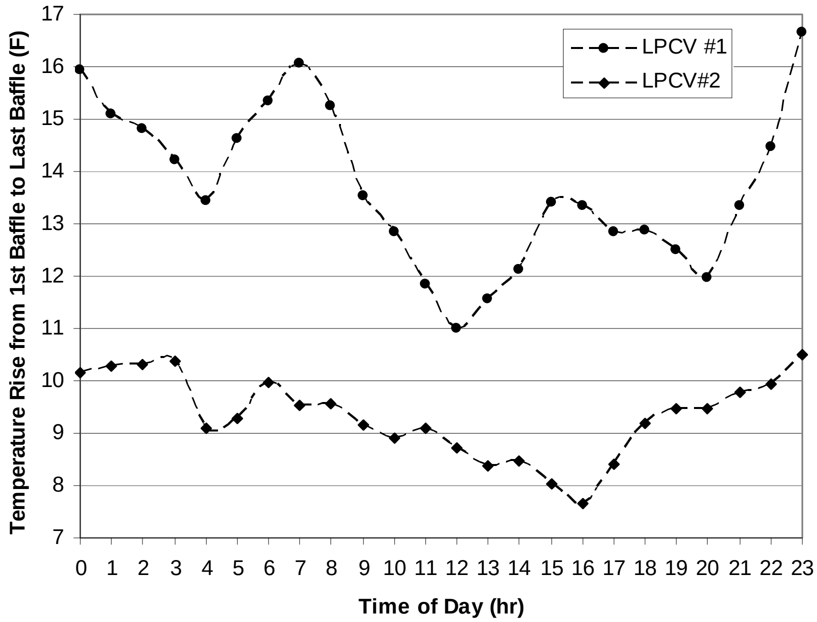

Figure 8: Temperature Rise from the First to Last Baffle in 400-foot wide LPCV Buildings in the Winter of 2008 in Iowa

BUILDING: END WALL CONSIDERATIONS - DOORS

The first LPCV building constructed by MCC had doors at the end of each alley on both ends of the building. These doors provide easy access for equipment entering the alleys, and they also serve as an emergency ventilation option should the back-up generator fail to operate. Opening doors during a ventilation failure enables air movement through the building or an emergency escape passage for cows.

Some important considerations regarding doors are the initial fixed cost and the annual repair cost due to damage by mobile equipment. A popular solution is to install doors only at each end of the feed alleys, therefore reducing the doors per 4-row section from 10 to 2. Access to the cow alleys is provided by extending the building 30 feet on each end for an equipment lane. This provides adequate space to maneuver tractors and sand wagons in and out of the cow alleys, but truck-mounted equipment may have difficulty maneuvering this turn. Another option to reduce cost is to place doors only on the feed alleys at one end of the building and add a 50-foot bay at the other end. This option enables truck-mounted equipment to enter the building at one end of a feed alley and exit on the other end via an additional feed alley. The number of doors per 8 rows of freestalls may be reduced from 20 to 2 if the building length is extended to truck maneuvering. Another advantage of this option is the elimination of exterior roads to the feed center from one end of the building.

Any decision involving doors also needs to consider the number of lost freestalls. The initial and annual cost of the doors must be weighed against the loss of 12 freestalls per each row of stalls. If space is limited, then the installation of doors may allow more stalls and cows per pen. If pen size is small, then the square footage per stall may be reduced 5-10% if doors are installed at each alley rather than adding extra space on each end of the building.

BUILDING: MANURE HANDLING

Most LPCV buildings currently use a scrape-flush plume system for manure handling. Manure is scraped to a center plume, and then water moves the sand-filled manure to a sand separation system. The plume is typically 2-3 feet in the ground at the upper end with a 1-2% slope, but it could also be 8-12 feet in the ground at the lower end in a wide LPCV building. The deeper plume requires extra cost during construction due to OSHA open-trench regulations, and additional design considerations are needed once a building is exited. Topography may require a pump in the manure pit to be 16-20 feet in the ground prior to lifting the manure stream up to solid-separation equipment. Gravity flow systems may not function as well since more elevation difference is required between the top of the plume and the top of a lagoon.

Several dairies flush alleys as a manure removal system. A 1½-2% floor slope is recommended for flushing sand-laden manure. A building manufacturer should be contacted prior to making the decision to flush a building. They may limit building width in order to efficiently handle a rain and snow load on the roof, or they may require a different type of roof seam. These loads on sloping buildings do not slide perpendicularly off the roof which changes the structural characteristics.

MILK PARLOR

One of the main challenges with LPCV facilities is integrating the ventilation of the milking center (parlor and holding pen) with the housing area. Parlor and housing layout are either "T" or "H" configurations currently used with naturally ventilated freestall buildings. Baffles are used in the housing area to increase air velocity within the cow resting space, but they are not practical in the holding pen due to the crowd-gate mechanism and required equipment accessibility for cleaning. In addition, most holding pens are a clear-span design, so additional structural supports are required if baffles are installed.

Cross ventilation and evaporative cooling of the holding pen are more difficult since the building is not enclosed on the 3 non-fan sides, and evaporative cooling requires an enclosed building. Fans pull air from the area of least resistance, so they often pull air from the housing or milking area rather than the sidewall inlet if these offer least resistance. However, cow movement in and out of the milking and housing areas prevent complete enclosure needed to pull air through an evaporative cooling system. Some new facilities increase the width of the holding pen and place the "special needs" pens alongside it. The evaporative cooling system is also placed next to the holding pen, and baffles are installed in the "special needs" area. This placement allows the coolest air to contact cows in the holding pen first. Evaporative cooling systems are also often installed in the parlor area to move cool air across employees and cows. In summer months air flowing between the milk parlor and holding pen entrance should be cooled prior to moving across the holding pen.

The current recommendation is to continue with naturally ventilated holding pens where heat abatement is accomplished through fans and low-pressure soaker systems. Consideration in designing the parlor ventilation system must also include milker preference as well as cow comfort. Ways to efficiently cool the environment in the worker area are still being considered.

NOISE LEVELS

Equipment operating inside an LPCV building does not appear to generate excessive noise according to measurements taken using a Scott 451 Sound Level Meter. The meter was set on the "A weighted scale and fast" response. Measurements were taken at 14-25 points along the center line of the south and north feed lanes. Average noise levels inside the building were less than 65 decibels, regardless of the number of fans in operation, as shown in Figure 9. Noise levels were below the acceptable OSHA sound level limit of 80 decibels for an 8-hour exposure limit. However, noise levels were 1-4 decibels higher in the north alley which was closer to the fans than the south alley. As the number of operating fans increased, the noise level increased as well.

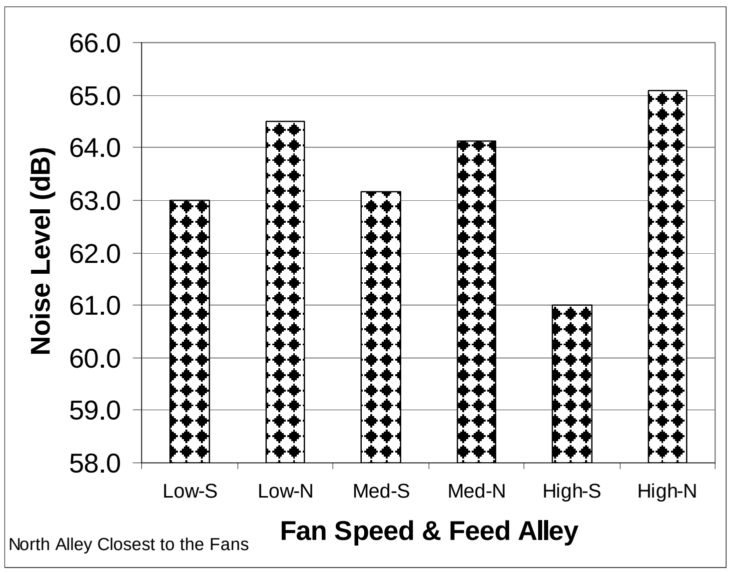

Figure 9: Noise Level Based on Fan Speed and Feed Alley

CONCLUSION

The optimum design and operation of low profile cross ventilated freestall facilities is still not fully understood. It is clear, though, that these facilities provide many potential benefits to dairy producers. One of these benefits is the ability to control the cows' environment during all seasons of the year. The biggest challenge appears to be efficiently managing the buildings during winter months. LPCV facilities have tremendous potential, but reasonable expectations should be considered when designing them for a specific climate. Design challenges remain as producers seek to optimize these facilities to meet their financial and cow comfort goals.

REFERENCE

Berry, I.A., M.D. Shanklin and H.D. Johnson. 1964. Dairy shelter design. Transaction of ASAE (7):3. pp 329-331.