Low-Profile Cross-Ventilated Freestall Facilities – A 2 Year Summary

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INTRODUCTION

Some dairies have constructed low-profile cross-ventilated (**LPCV**) housing facilities during the past 2 yr. The MCC dairy group in South Dakota placed into operation the first LPCV wide building in fall 2005. Previously this group, and maybe others, had utilized cross ventilation in a remodeled 4-row facility prior to construction of an 8-row building. The LPCV buildings are under construction or operating currently in 7 other states and being considered in 10 additional states. Across North America, the concept of LPCV has been extended from 8- to 24- row wide buildings. Buildings with 12 and 16 rows of freestalls currently are the common choices.

Figure 1 shows an end view of an 8-row LPCV building. Evaporative cooling pads are placed along one side of the building and fans are placed on the opposite side. There is more space available for placement of fans and evaporative pads parallel to the ridge rather than perpendicular, because the equipment doors are located in the end walls. Figure 2 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 for natural ventilation. One potential advantage of the LPCV or tunnel-ventilated buildings is cows are exposed to near constant wind speeds. Inside the building the air velocity or wind speed are normally less than 8 mph during peak airflow. The ventilation rate is reduced during cold weather with the wind speed reduced to less than 2 mph.

The air quality inside the LPCV building was evaluated during 2 study periods in 2006 at the MCC dairy group's ND facility. Particulate emissions from the 3 samplers were 78.2 ppm near the east end of the barn, 74.8 ppm in the barn's center, and 94.8 ppm near the west barn end. These values are between 10 to 100 times less than dust concentrations from poultry and swine units (Jerez et al., 2006). By comparison, U.S. Environmental Protection Agency (**USEPA**, 1987) National Ambient Air Quality Standards (**NAAQS**) limits primary and secondary PM_{10} dust concentration for a 24-hr average sampling period to 150 ppm. The purpose of the primary standard was protection of public health and the secondary standard is to protect the public from known or anticipated adverse effects. The values obtained from this site are below the current standard. Dust emissions were collected in an LPCV using sand bedding. Further research is needed to investigate if dust emissions would be higher if organic bedding, such as dried manure solids or sawdust, is used.

Gas emission rates were estimated using an open-path ultraviolet (**UV**) spectrometer system. Gases emitted from the LPCV were found to be dominated by nitrogen-based gases (NH_3, NO_2, NO) during the spring and summer testing periods. Ammonia concentrations and emission rates were found to be greatest during the springtime and under the lowest ventilation rate tested (420,000 cfm; Table 1). Average

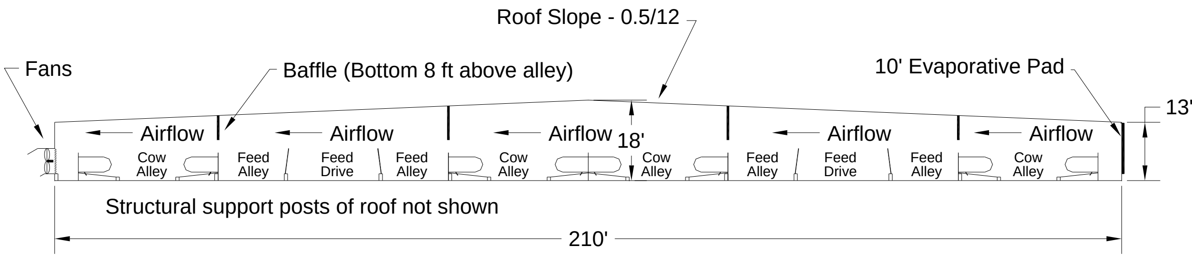

Figure 1. End view of an 8-row low-profile cross-ventilated freestall building.

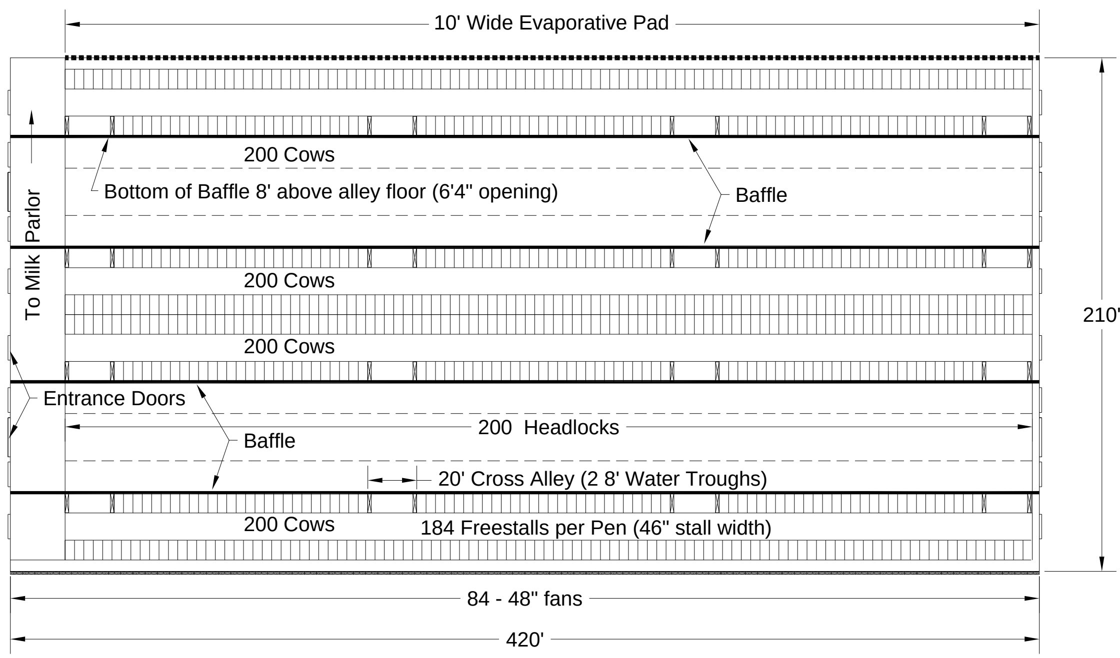

Figure 2. Top view of a typical layout of an 8-row low-profile cross-ventilated freestall building. The building length is adjustable based on cow numbers.

Table 1. Mean gaseous concentration and emissions from an 800-cow low-profile cross-ventilated dairy barn.

Season	Ventilation Rate	NH_3 (ppb)	NO_2 (ppb)	NO (ppb)
Spring	Low	1,370	445[a]	8[ab]
	Medium	1,181[b]	296	27
	High	1,108 [a]	417[a]	0[a]
Summer	Low	1,084[a]	176[b]	0[a]
	Medium	1,157[b]	145[b]	4[b]
	High	1,112[a]	155[b]	0[a]

[abc] within a column, means without a common superscript differ ($P < 0.05$) using differences in Least Squares Means

concentrations of NH_3 observed here (spring = 1219 ± 5 ppb; summer = 1117 ± 4 ppb) were lower than those reported by Zhoa et al. (2005) and Mutula et al. (2004) of 0.3 – 3.0 ppm and 36 – 51 ppm, from naturally ventilated freestall barns in Ohio and Texas, respectively.

DESIGN CONSIDERATIONS

Positive factors of LPCV include lower roof line, smaller footprint for buildings, shorter walking distance to and from the parlor, controlled lighting, and improved animal and worker environment. However, there are design considerations where variable solutions are being implemented as more of these buildings are constructed. This paper outlines areas where optimal solutions have not been identified in LPCV buildings.

Building: Width

During warm weather, the air exchange rate is 60 to 120 sec. An air exchange is equivalent to replacing all of the air inside the building with fresh air. If the air exchange rate is 60 sec, then every 60 sec the fans are moving enough air to completely exchange the air inside the building with outdoor air. The air exchanged is reduced during the winter months. An 800-cow LPCV building in ND currently has a winter-time exchange rate of 180 to 240 sec. Winter ventilation rates must remove moisture to minimize condensation and prevent gases, such as ammonia, from becoming a problem. The ND facility manages airflow rates based on the ability to smell ammonia rather than air temperatures, which results in higher winter time ventilation rates than some dairies are using.

Building widths of LPCV range from 200 to 500 ft. There are buildings with nominal width of 200 (8-row), 250 (10-row), 300 (12-row), 400 (16-row) and 500 ft (24-row). Table 2 shows the air exchange time based on a 10 ft evaporative pad/running ft of building length and different velocities through the pad. Manufacturer's recommended a maximum velocity of 400 ft/min (**fpm**) through the pad. Velocities higher than 400 fpm result in a decrease in pad efficiency. Originally the targeted air exchange rate through the building was 120 sec or less. Buildings wider than 300 ft have exchange rates of 180 to 240 sec depending on the pad velocity. As pad velocity increases, the pad efficiency reduction results in a higher temperature.

The K-State Dairy team evaluated 4 LPCV buildings in the summer of 2007. Table 2 is a summary of the temperature rise across the building during the period of July 17 to August 16, 2007. The data indicates the average temperature rise between baffles is 0.58 ^oF and the average temperature rise across the building is 0.0092 ^oF/ft of building width. The temperature rise across the building is approximately 1 ^oF/ per 100 ft of building width. Since the building humidity is high due to the evaporative cooling system, there is approximately a 1 unit increase in the temperature humidity index (**THI**)/100 ft of building width.

Building: End Wall Considerations - Doors

The first LPCV building had doors located on each end of cow and feed truck alleys. The doors provide easy access for equipment to enter and exit each alley. They also serve as an emergency ventilation option should the back up generator fail to operate. Opening doors during a ventilation failure enables some air movement through the complex or an escape passage for cows. The main concerns with the doors are the

Table 2. Comparison of the impact of building width and air velocity through the evaporative pad have on the air exchange rate (sec/exchange).

Air Velocity through the Evaporative Pad (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).

initial fixed cost and the annual repair cost due to damage by mobile equipment. A popular alternative is to install doors only at each end of the feed alleys, reducing the doors per 4 rows (assuming 4-row freestall design) of freestalls section from 10 to 2. Access to the cow alleys is provided by extending the building 30 ft on each end. This provides adequate space to maneuver tractors and sand wagons in and out of the cow alleys. Truck mounted equipment will have difficulty maneuvering the tight turn radii.

Another option is placement of doors only on one end of the building and adding a 50 ft bay at the other end of the building. This enables truck mounted equipment to enter the building at one end of a feed alley and exit on the other end via another feed alley and back out the building. This reduces the doors per 8 rows of freestalls from 20 or 4 to 2. The decisions involving doors 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/each row of stalls. If space is

Table 3. Average temperature rise between baffles and per ft of building width observed in four low-profile cross-ventilated buildings in the upper Midwest in summer 2007.

Dairy ID	Average Temperature Rise (^{o}F) between Baffles*	Average Temperature (^{o}F) Rise/Ft 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/dairy is based on 2,880 hourly average measurements including nighttime data.

limited, then installation of the doors may allow more stalls and cows/pen. If pen size is small, then the building square footage/stall may be reduced 5 to 10 % if doors are installed at each alley rather than adding extra space on each end of the building.

Building: Insulation

Insulating the roof and walls requires a significant investment/cow. There are 3 types of insulation being used: spray-in-place, fiberglass, and rigid board. Insulation is necessary during the summer months to reduce the radiant heat load and during the winter to minimize condensation problems. Solar radiation causes the metal roof to warm and transfer heat below the surface into the cow living area. Naturally ventilated freestall buildings, normally uninsulated, have 4/12 roof slopes; which enables warm air to rise and escape the ridge opening. In a LPCV building the heat has to be exhausted through the fans. The air exchange rate should be sufficiently high during the summer that no noticeable temperature rise occurs inside the building. During the winter, condensation occurs when warm moist air contacts a cold metal surface resulting in moisture dripping back into the housing area. The metal surface may be the roof, fasteners that penetrate the roof, or metal purlins.

The least cost insulation appears to be the flexible fiberglass insulation that is commonly used in insulating metal buildings. Most metal building contractors are familiar with the recommended installation procedures for flexible fiberglass insulation. However, the seams are often not sealed in normal warehouse or manufacturing applications of these buildings. The excess moisture in LPCV, due to normal cow respiratory activity and urine, requires the seams to be sealed. Unsealed seams allow moisture to become trapped between the roof and insulation causing the material to sag. Once sagging becomes a problem, the insulation pulls away from the roof, allowing more warm moist air to come in contact with a cold metal roof causing condensation. The problem will continue until the insulation fails. Also, the high velocity hot air exiting the exhaust pipe from a tractor may cause problems.

Close-cell, rigid and semi-flexible open cell are the two basic types of spray on insulations. Spray on insulation has the ability to seal cracks and conform to odd shapes. Close-cell insulation will weigh 1.5 to 2 lb/ft^3 (**pcf**) and have an R-value of around 6/in of thickness. This material expands to 35 to 50 times its original volume. The open cell insulation will have a final weight of 0.4 to 0.6 pcf when fully cured and will expand about 150 times its original volume. The R-value will be around 3.5/in thickness. Spray foam, like most organic materials, is combustible; but is formulated with flame retardants to decrease flame spread. The open cell material may allow moisture to enter the foam where the close-cell resists water absorption. One disadvantage of the close-cell is the maximum thickness applied/pass is generally limited to 0.5 to 1.5 in, where the open cell may be applied in one pass.

Another option being considered is rigid board insulation. Typically this insulating board has a white surface. This enhances light reflexivity and is washable with a high-pressure system. Thickness ranges from ½ to 3 in with a R-value of 6/in thickness. One challenge with this material is the nominal dimensions are 4 ft by 8 ft or 4 ft by 10 ft for each sheet. Therefore, the purlin spacing has to work with the joints of the board.

Building: Manure Handling

Currently most LPCV buildings have utilized a scrape flush plume system for manure handling. Manure is scraped to a center plume and then water moves the sand laden manure to a sand separation system. Due to parlor efficiency and shorter walking distances, larger pen sizes are presenting challenges in providing adequate time away from the pen to clean alleys and groom or bed stalls.

The impact of pen size and number of pens was modeled using a 3,300 cow dairy with a 72 stall rotary milking 3X/day with a steady state throughput of 463 cows/hr. Manure is assumed to be scraped with an 8 ft diameter rubber tire operating at 5 mph and 60 % efficiency (must allow time to open gates and turn) by a single operator. Cows were assumed to produce 150 lb of manure/d. In option 1, there were 12 pens with 275 cows/pen and pen length of 610 ft. Total daily manure production in option 1 is 36,750 lb/d/pen. Scraping 2X/d results in 42 min to clean the alleys and 36 min to milk the pen of cows. Option 2 has 8 pens with 412 cows/pen and pen length of 900 ft. Total manure production/pen is 50,400 lb/d and scrape time is 90 min. However, only 54 min are required to milk the pen of cows. In this case, one operator would not be able to scrape each pen during a milk shift. Either a second operator is required or 3X scraping must be implemented. Scrape time in option 1 is reduced to 28 min and in option 2 to 62 min when scraping 3X/d. A second operator will be required in option 2, since even with 3X scraping the time required to scrape the alleys exceeds the time required to milk a pen. This example illustrates the importance of evaluating the manure handling options when making parlor and pen size decisions, particularly when using rubber tire scrapers. Also, employee management is critical, because there is no flex time built into the daily routine of scraping manure.

One dairy currently under construction will be flushing. A 2 % floor slope is recommended for flushing sand laden manure. Contacting a building manufacturer prior to making the decision to flush a building is the first step. They may limit building width to handle the rain and snow load on the roof or require a different type of roof seam. These loads on sloping buildings do not slide perpendicular off the roof, which may change the structural characteristics. Also, evaporative pads must be installed nearly level, to function properly. The alleys are sloped, while the ridge line is nearly level on plans reviewed of dairies considering flush systems. The stem walls along the side vary in height. This helps prevent some of the roof load issues as well as installation problems of the evaporative pad.

There appears to be a trend toward the 400 ft wide building, because of the traditional thought of 8 milking groups through a parlor. As pen sizes increase and alleys get longer, there may need to be some consideration given to using 12 pens to ensure adequate time for cleaning alleys and grooming stalls while the cows are at the parlor.

Lighting

Proper lighting in LPCV building is important, because no natural light exists. Research indicates that 10 to 15 foot candles (**fc**) of light are necessary for milk production (Dahl, 2001). High and low bay metal halide light fixtures may not be suitable because of lower fixture mounting heights. Mounting height is determined by the distance from the bottom of the fixture to the work surface. In a freestall building, the work surface is better defined by the top of the freestall loops or about 4 ft above the floor. Most metal halide lights recommend the mounting height be 12 to 20 ft, depending on the fixture, for optimum light distribution. The mounting height for florescent lights is 6 to 12 ft, which is better suited for the LPCV buildings. The study barn had two rows of fluorescent lights/pen.

The fixtures each contained two – 8 ft florescent tubes, mounted at a height of approximately 10 ft above the concrete alley. Fixtures were located approximately 20 ft on center and in the center of the cow alleys. Light measurements in Figure 3 represent the average of the 10 readings along the pen length. The average illumination for the building was 27.9 fc with a range from 9.9 to 44.8 fc. With exception of the stalls next to the pads and fans, light levels are within or exceed the recommended light levels. The lighting should provide 25 fc of light throughout the building, rather than the recommended 10 to 15 fc. Bulb lumens or light output tends to decrease over time, especially as fixtures accumulate dust and fly specks. Additional lighting in the building also creates a better environment for employees to perform their tasks.

Some dairies have installed metal halide light fixtures, typically 30 ft on center. Visual observation of these buildings suggests non-uniform lumens throughout the pens even though the fixtures may have adequate lumens. The non-uniform lighting is typically a result of an increased spacing-to-mounting height ratio. Generally, the spacing-to-mounting height ratio should be 2 or less. If there is a preference for metal halide lights, one option to consider is the metal halide light fixtures used in parking garages. These units have a smaller wattage bulb resulting in more fixtures, but the mounting height for these fixtures is similar to florescent fixtures. The fixture lens allows light to emit from the sides and bottom. The metal halide fixtures currently used in the dairy industry emit light only from the bottom of the lens.

A system will have to be determined to provide long day lighting for lactating cows and short day lighting for dry cows. Some are installing single tube fixtures or utilizing fixtures which reduce the number of florescent tubes on while maintaining 5 fc throughout the building. These options require installing additional circuits to implement the long day light management strategies. Adequate low level lighting is necessary to enable employees to safely and efficiently perform routine task.

Milk Parlor

One of the main challenges with LPCV is integrating the ventilation of the milk center (parlor and holding pen) with the housing area. Parlor and housing layout are of the “T” or “H” configurations currently used with naturally ventilated freestall buildings. Evaporative cooling basically requires an enclosed building. Baffles in the housing are used to increase the air velocity within the cow resting space. Baffles are not practical in the holding pen due to the crowd gate mechanism and accessibility required by equipment for cleaning. In addition, most holding pens are clear span design, so additional structural supports are required if baffles are installed. Cross ventilation and evaporative cooling of the holding pen area is more difficult since the building is not enclosed on the three non-fan

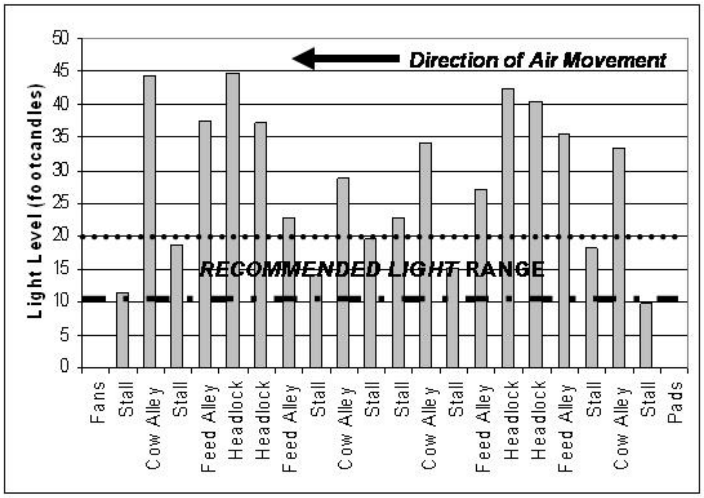

Figure 3. Distribution of light by location across an 8-row low-profile cross-ventilated barn.

sides. Fans will pull air from the area of least resistance. Fans may pull air from the housing or milking area rather than the sidewall inlet, if these areas are paths of least resistance. Cow movement in and out of the milk area and the housing area prevent these areas from being closed off to ensure the air is pulled through an evaporative cooling system. Some new facilities are increasing the width of the holding pen structure and placing the special needs pens beside the holding pen. The evaporative cooling system is placed along side the holding pen and baffles are installed in the special needs area. This results in the coolest air contacting cows in the holding pen first. Evaporative cooling systems are also installed in the parlor area to move cool air across employees and cows. Air moving between the milk parlor and holding pen entrance should be cooled prior to moving across the holding pen.

The current recommendation is probably to continue with naturally ventilating the holding pen. Heat abatement is accomplished by fans and low pressure soaker systems. Consideration in designing the parlor ventilation system must include milker preference as well as cow comfort. Many are considering ways to cool the environment in the worker area.

Ventilation: Design

Current ventilation design of LPCV buildings is generally controlled by the evaporative pad on the inlet size. Manufacturers of pads recommend a maximum air velocity through a pad of 400 ft^3/min (**cfm**)/ft^2 of pad area. Generally, 350 to 375 cfm/ft^2 is used as a design value for the air speed through a pad. A 13 to 14 ft sidewall is necessary to install a 10 ft tall pad. Increasing the building height to accommodate two 6 ft pads may not provide additional benefits. The maximum fan airflow/ft of building length is 4,000 cfm assuming a 10 ft pad and 400 cfm/ft^2 of pad area. Fan capacity may be greater but the efficiency of the pad is reduced, resulting in a decline in air temperature from the inlet to outlet side of the pad. If an evaporative pad is not installed, the air velocity through the inlet sidewall may be increased to 600 cfm/ft^2 of sidewall opening.

The fans encounter resistance as they try to pull air across the width of a building. This is known as static pressure and is measured in *inches of water* using a manometer. Each baffle or obstacle increases the static pressure. Livestock ventilation fans operate in the range of 0 to 0.2 in of static pressure. Maximum operating static pressure in a LPCV should be limited to 0.15 in or less. Understanding the static pressure issues is critical during the spring and fall of the year when the number of fans operating is variable. If the inlet opening is inadequate, then the static pressure increases and may cause the fans to stall (turn but no air movement). The first LPCV buildings had open breezeways to the parlor, which acted as inlets even though the evaporative pads may have been closed. There is still much debate on whether to cover the evaporative pads during the winter or allow them to remain open. If the pads are not covered, then increasing the number of fans on does not increase static pressure. A winter inlet is required if the pads are covered. Additional air inlets are required in the spring and fall or anytime additional fans are turned on when the baffles are covered. As a general rule of thumb, for each fan operating, a minimum of 50 ft^2 of inlet area is required.

Ventilation: Winter

Guidelines for operating fans during the winter are relatively unknown. Currently each dairy appears to have different guidelines; however there seem to be two operational modes. The first mode decreases the air exchange rate (turning off fans) to prevent frozen manure on the alleys. This strategy prevents potential lameness problems, but probably leads to an increase in ammonia levels inside the building. In addition, there may be an increase in moisture due to condensation caused by the temperature difference inside the building and exterior metal surfaces. Moisture may condense on non-insulated metal surfaces, such as a purlin or the roof. Moisture condensation is a result of warm, moist air coming in contact with a cold surface. The second mode of action utilizes a controller to operate fans based on temperature along the inlet side of the building. This mode typically sets a minimum number of fans that operate below a minimal set point temperature. As outdoor air temperature declines, the number of fans on remains constant resulting in a colder temperature inside the building and potential frozen manure problems. This also results in employees being exposed to colder temperatures at minimum air speed.

There does appear to be some agreement that an 8 min air exchange is the maximum air exchange rate based on conversations/comments and visual observations. A 16-row facility will require twice as many fans (assuming equal number of fans) operating when comparing fan operational procedures during the winter between 8- and 16-row facilities. This additional air requirement during the winter months in a 16-row facility results in the sidewall inlet opening having to be twice as large when compared to an 8-row building. Also, the first 200 ft of building width may be colder since more air must be pulled through the inlets to obtain the 8 min air exchange rate. The air will not warm up as rapidly in a 16-row facility as compared to an 8-row facility during the winter months, if the air exchange rate is equal. During extremely cold weather, more manure may freeze on the alleys closest to the air inlet in a 16-row LPCV. Another consideration is how the winter inlets will be managed during periods of snowfall. Pulling the air through an open inlet during snow events will result in a significant amount of snow in the first pen of cows. The air could be pulled through the pad when it is snowing to prevent snow from entering the barn. However, this strategy may reduce pad life.

The winter inlet should be near the top of the sidewall to allow cold air a chance to warm prior to contacting the cows or alleys. Another option is to use a split curtain covering the pad. Typically, the curtains are split in the middle with the top curtain rolling upward and the lower curtain rolling downward. This creates an inlet in the middle of the pad and the top curtain 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 to allow the air inlet to be near the top of a pad. The other option, when using a single curtain, is to install an 18 to 24 in wide inlet above the curtain. Placement of the inlet at the bottom of the pad results in cold air immediately contacting cows and alleys. When snow and ice cover the inlet, the inlet has to be raised.

Ventilation: Baffles

The interior of a LPCV building is very similar to a natural ventilated freestall. One exception is the addition of baffles to divert air from the head space back into the stall area. The first several LPCV buildings were constructed with baffles; however there has been a recent trend toward eliminating the baffles to reduce the cost and baffle damage by equipment. Baffles result in the air speed in the stall area being increased from 2 to 3 mph to 6 to 8 mph depending on the number of baffles. Operators of skid steer equipment used to scrape manure occasionally maneuver the equipment in such a manner that baffles are damaged. Some dairies have opted 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. One dairy that initially opted not to install baffles, installed baffles in the summer 2007. They observed better lay down rates of cows once a baffle was installed between head-to-head rows of free stalls. They reported a corresponding increase in milk production after baffle installation as well. Research indicates that cows need at least 12 hr of rest/d. Each hour less than 12 hr of rest results in a 2 lb/d decline in milk production. A similar response is suggested for each hour above 12 hr of rest.

The baffle opening is a function of air velocity through the building and number of baffles. It appears the static pressure drop across a baffle may be approximated using the Pitot tube static pressure equation. Baffle design is critical in minimizing the static pressure encountered by the fans. As static pressure increases, fan performance decreases. Practically speaking the bottom of the baffle may not extend much below 7 ft from the floor due to cow and equipment contact. Economically, it is not practical to obtain a 5 mph or greater breeze in a LPCV building without baffles. At least twice as many fans are required, resulting in higher summertime operating cost. The initial cost and continual operating cost of the additional fans must be compared against the cost of baffles. Baffles should have minimal long-term operating or variable cost

Evaporative Pad vs High-Pressure Mist

Evaporative cooling is the result of warm air coming in contact with a high-pressure stream of moisture or a wetted surface. The air temperature decreases and the humidity increases as moisture is added. Theoretically, the lowest air temperature obtainable occurs when the air is 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 2 air streams are at the same temperature, but different relative humidity; the stream with the lower humidity will cool lower than the stream with a high humidity. Since the outdoor air temperature constantly changes, the exhaust temperature from the pad also changes.

Heat stress abatement requires extra water during the summer for low-pressure fence line soaker or evaporative cooling systems. Evaporative cooling is currently the preferred method for cooling LPCV buildings. However, at least one dairy has installed a high-pressure mist system. Design criteria for the evaporative cooling assumes no heat is added or lost from the air. The cooling potential is a function of the air's ability to absorb moisture. Lower relative humidity results in potentially a lower air temperature. Evaporative pads and high-pressure misters are currently the two methods used to add moisture to the air. The high-pressure mist system sprays fine droplets of water into the air stream. The evaporative pad sprays water onto a cellulous material. The pad has channels through the cellulous material that allow the air to come in contact with moisture as it passes through the openings. Figure 4 shows the hourly average temperature differences from July 17 to August 16, 2007 between the temperature at the first baffle in a LPCV building with evaporative pads and ambient air. This difference illustrates the cooling potential of an evaporative pad. The evaporative pad was able to cool the air 8 to 13 ^{o}F during the afternoon hours. The cooling potential increased as the relative humidity decreased during the afternoon hours.

The authors have not collected data from LPCV facilities with high-pressure mist systems; however, the authors have worked with high-pressure mist systems in naturally ventilated facilities and tunnel ventilated structures. We have worked with evaporative pads in LPCV facilities to determine water usage and changes in temperature, humidity, and THI. Water usage by evaporative pad ranges from 0.3 to 0.4 gal/hr/ft^2 of pad area. Most assume similar efficiencies between evaporative pads and high-pressure mist systems. Design efficiencies of 70 to 80 % are commonly used. A typical nozzle with a high-pressure mist system has a typical flow rate of 0.03 gpm (high volume nozzle) or 1.8 gph. At 75 % efficiency, the actual water absorbed by the air equates to 1.4 gph. Therefore, one high-pressure mist nozzle is equal to 4 ft^2 of evaporative pad, assuming equal efficiencies. Per running foot of building length, either a 10 ft evaporative pad is required or approximately 2 1/2 high-pressure nozzles. The construction of an evaporative pad necessitates equal distribution of the air through the pad and uniform temperature drops. The high-pressure mist system sprays the water down into the air stream, so the potential exists for non-uniform temperature drops of the air from top to bottom along the sidewall heights. In tunnel ventilated freestalls, this problem may have been overcome by installing multiple rows of nozzles. As air passes each row of nozzles, the droplets fall further down into the air stream, until the air is able to absorb moisture. The multiple rows of nozzles allow a controller to stage the quantity of water sprayed into air stream based on ambient humidity. The automated controller controls the number of nozzles operating and spraying moisture into the air

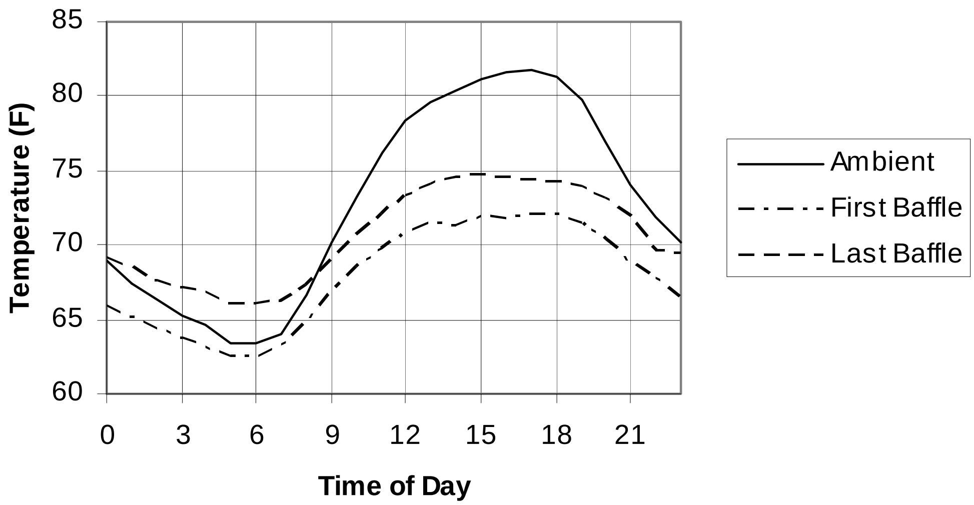

Figure 4. Average hourly temperatures at different locations in a low-profile cross-ventilated freestall building between July 17 and August 16, 2007.

stream based on ambient relative humidity. One company assumes the air temperature exiting the high-pressure mist system will equal the wet bulb temperature minus 3 ^{o}F. At 100 % relative humidity, the wet bulb temperature equals the dry bulb (ambient) temperature. Current research data, open to the public, is not available to verify this design parameter. The high-pressure system does provide an open sidewall with a curtain controlled inlet from September to May and some natural light to penetrate into the building.

The amount of water used per ft^2 of evaporative pad for a dairy in Kansas was compared to the study dairy in ND. Similar water usage was observed between the Kansas dairy and the medium airflow rate at the ND dairy (Figure 5). Measured

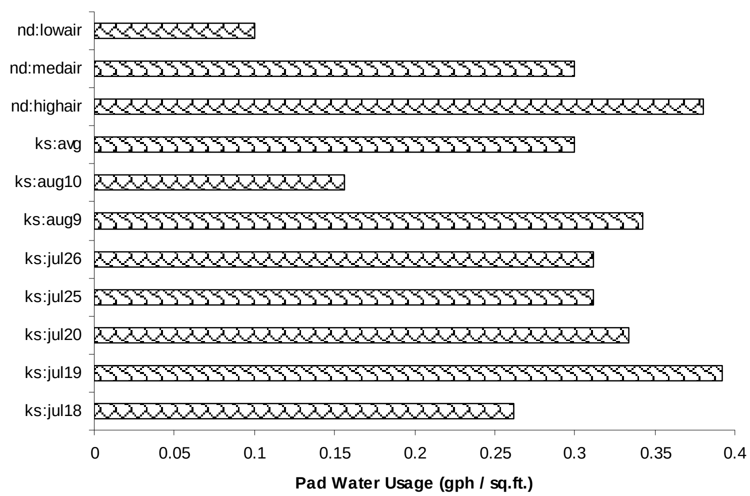

Figure 5. Comparison of evaporative pad water usage during summer 2006 monitoring periods at a Kansas (ks) and North Dakota (nd) study dairy (gph/sq.ft. = gal/hr/ ft^2 of evaporative pad surface).

airflow rates were 320 fpm through the pads at the Kansas site and 282 fpm during the medium airflow rate study at the ND dairy. Water usage by the pad did not increase proportional to the airflow rate. When comparing the high and medium airflow rates, the difference in air velocity was 47 %; however, the increase in pad water usage was only 27 %. At the ND site measured airflow rates through the pad averaged 106, 185, and 282 fpm for the low, medium, and high airflows, respectively. On a per cow basis, water usage was 0.45, 1.37, and 1.75 gph/cow while the evaporative pad was operating. Consumptive water use equaled 30.1, 91.5, and 115.7 gal/15 minute for the low, medium, and high airflow rate studies, respectively.

CONCLUSIONS

Low-profile cross-ventilated freestall facilities are still in the early stages of understanding the optimum design and operation. It is clear that these facilities provide a lot of potential benefits to dairy producers. One of these benefits is the ability to control the cow's environment during all seasons of the year. The biggest challenge appears to be how to manage these structures during winter months. Low-profile cross-ventilated barns have tremendous potential; however, reasonable expectations should be considered when designing LPVC structures for a given climate. Design challenges remain as producers seek to optimize these facilities to meet their financial and cow comfort goals.

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