DAIRY HOUSING OF THE FUTURE

Opportunities with Low Profile Cross Ventilated Housing

SEPTEMBER 10—11, 2008

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Proceedings of the

Dairy Housing of the Future

Opportunities with Low Profile Cross Ventilated Housing

September 10 – 11, 2008

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DAIRY HOUSING OF THE FUTURE

Opportunities with Low Profile Cross Ventilated Housing

SEPTEMBER 10—11,

Wednesday, September 10

6:30 am	Registration
8:00 am	Welcome
8:10 am	Opportunities with Low Profile Cross Ventilation (LPCV) *John F. Smith, Kansas State University*
9:00 am	Design Considerations with LPCV *Joe Harner, Kansas State University*
9:45 am	Break
10:15 am	Fans: Airflow vs. Static Pressure *Joe Zulovich, University of Missouri*
11:00 am	Optimizing Airflow in Freestalls *Joe Harner, Kansas State University*
11:20 am	Options for Cooing the Air *Joe Harner, Kansas State University*
NOON	Lunch
1:00 pm	Air Quality: Odors & Dust *Ron Sheffield, Louisiana State University AgCenter*
1:45 pm	Creating Desirable Lighting *Joe Harner, Kansas State University*
2:15 pm	Dealing with Cold Weather *John F. Smith, Kansas State University*
2:40 pm	Issues with Insulation *Joe Harner, Kansas State University*
3:00 pm	Break
3:30 pm	Traffic Patterns in LPCV Facilities *Joe Harner, Kansas State University*
3:50 pm	Economic Considerations *Kevin Dhuyvetter, Kansas State University*
4:30 pm	Producer Panel
5:30 pm	Reception & Visit with Sponsors
7:00 pm	Adjourn

Thursday, September 11
Dairy Facility Tours

6:45 am	Load buses
7:00 am — 5:00 pm	Tour Low Profile Cross Ventilated Dairy Facilities

DAIRY TEAM
KANSAS STATE UNIVERSITY

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Dairy Housing of the Future

Opportunities with Low Profile Cross Ventilated Housing

We would like to thank the following individuals & organizations for their help in putting together a successful conference!

Rick Millner & MCC Dairy
Matt VanBaale & UltiMilk Dairy Co.
Gary Fehr & Fehr's Riverview Dairies
Kevin & Tonya VanWinkle & VanWinkle Dairy
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Wim Hammink & Global Dairy
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Charlotte Bruna
Cindy Casper
Tamara Robinson
with
Kansas State University

Holiday Inn City Centre
Prairie Coach Trailways

Opportunities with Low Profile Cross Ventilated Freestall Facilities

J. F. Smith, J. P. Harner, and B. J. Bradford, 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.

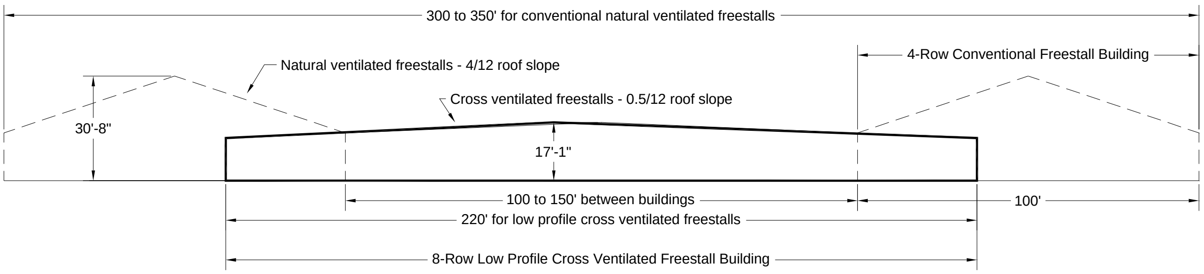

Figure 1: End Views of 8-row Naturally Ventilated Freestall Buildings and 8-row LPCV Freestall Building

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.

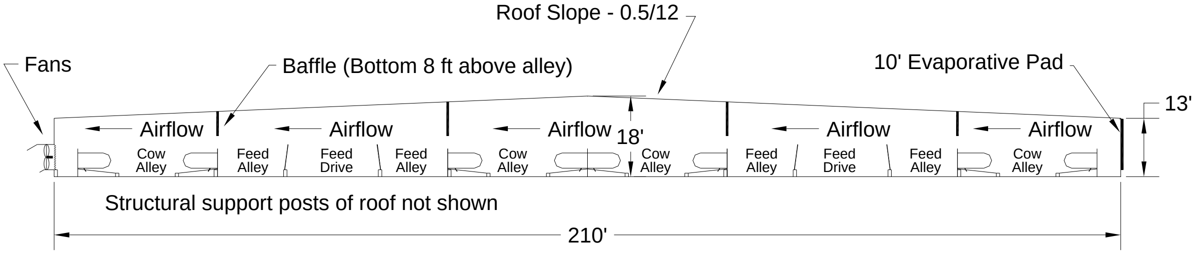

Figure 2: End View of an 8-row LPCV Freestall Building

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

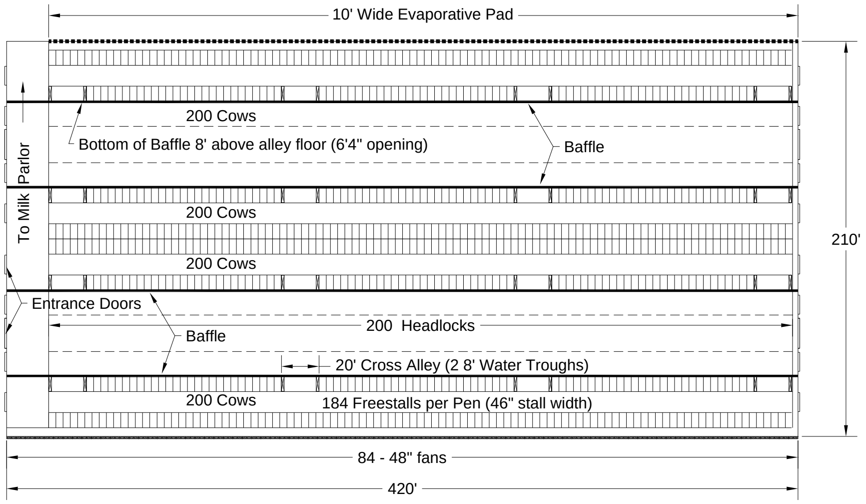

Figure 3: Top View of an 8-row LPCV Building (Adjustable Building Length Based on Cow Numbers)

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.

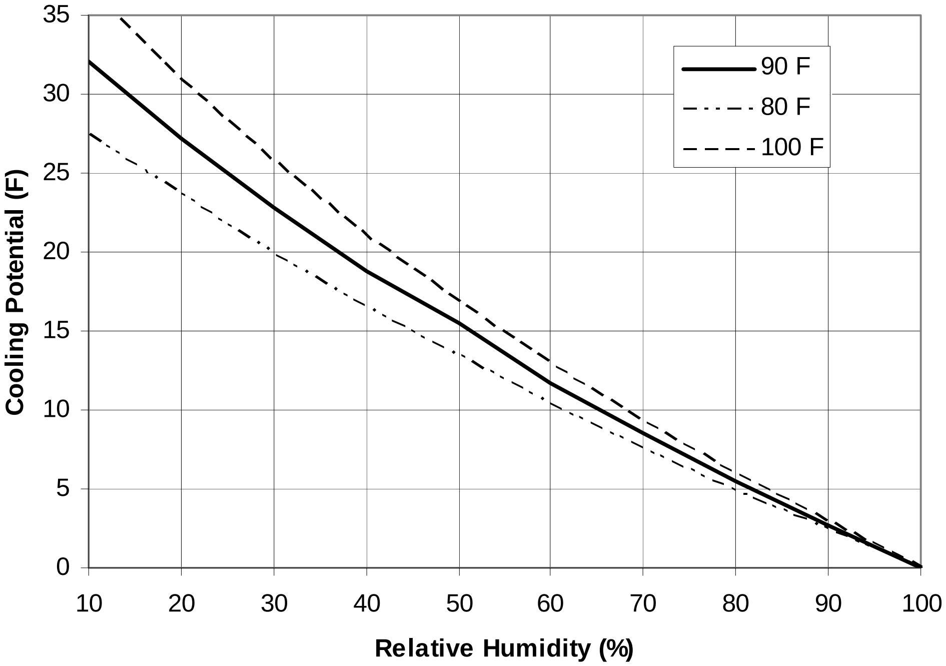

Figure 4: Impact of Relative Humidity and Temperature on Cooling Potential When Using an Evaporative Cooling System

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.

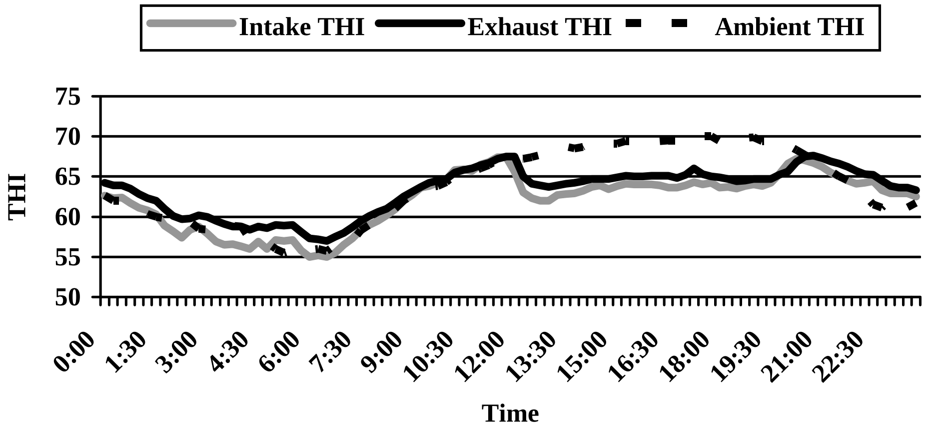

Figure 5: Cool Summer Conditions, Temperature (F) (7-4-06)

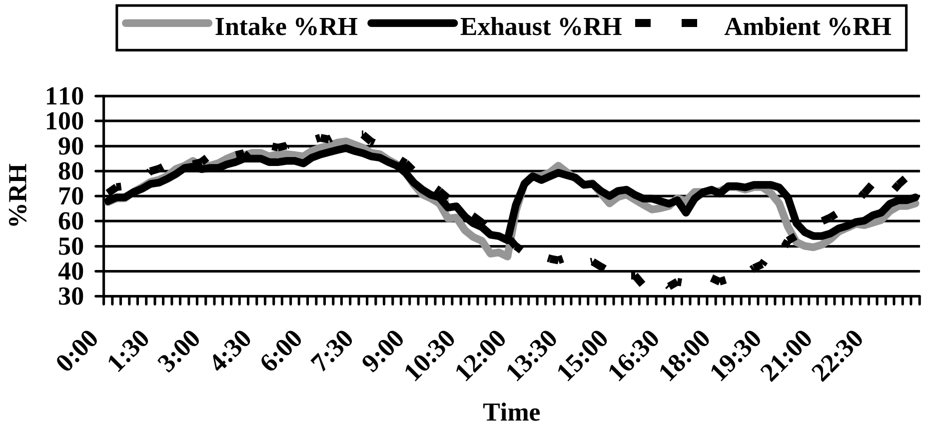

Figure 6: Cool Summer Conditions, Percentage of Relative Humidity (% RH) (7-4-06)

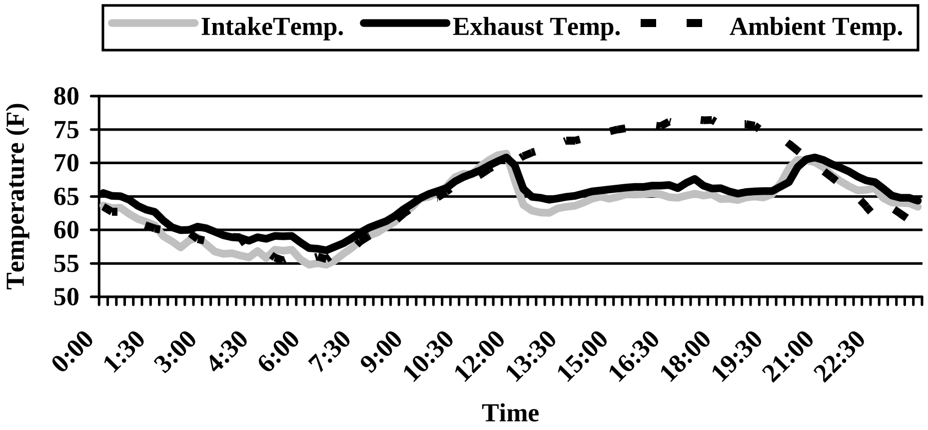

Figure 7: Cool Summer Conditions, THI (7-4-06)

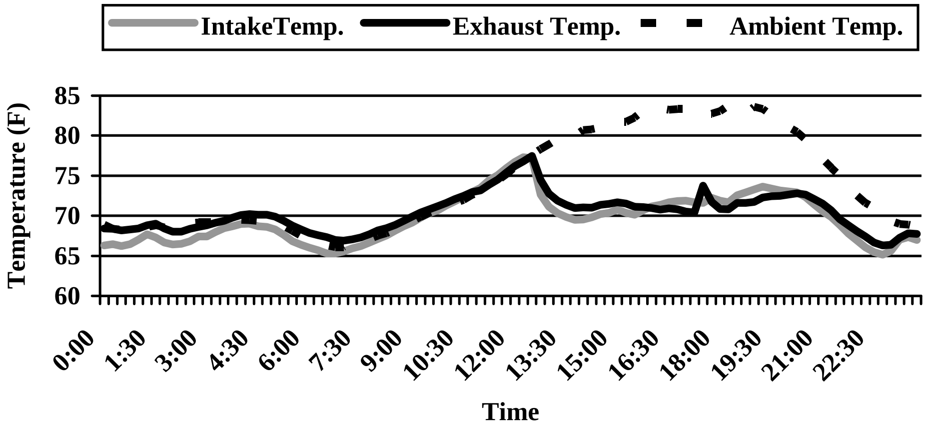

Figure 8: Average Summer Conditions (7-1-06)

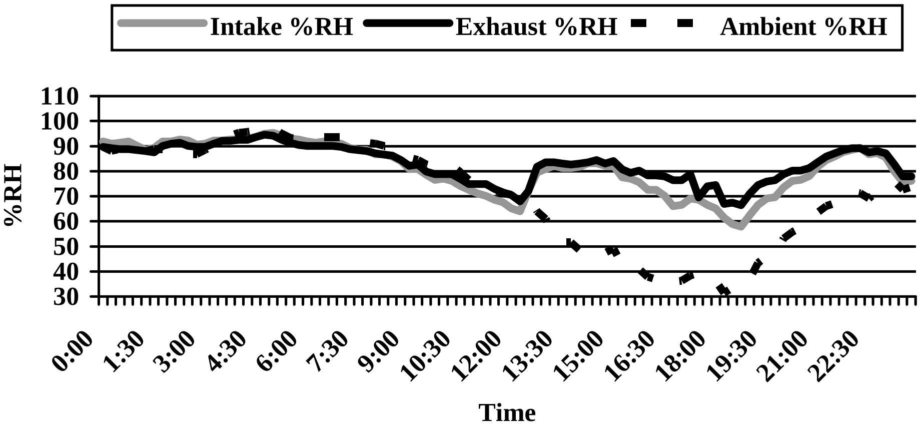

Figure 9: Average Summer Conditions, % RH (7-1-06)

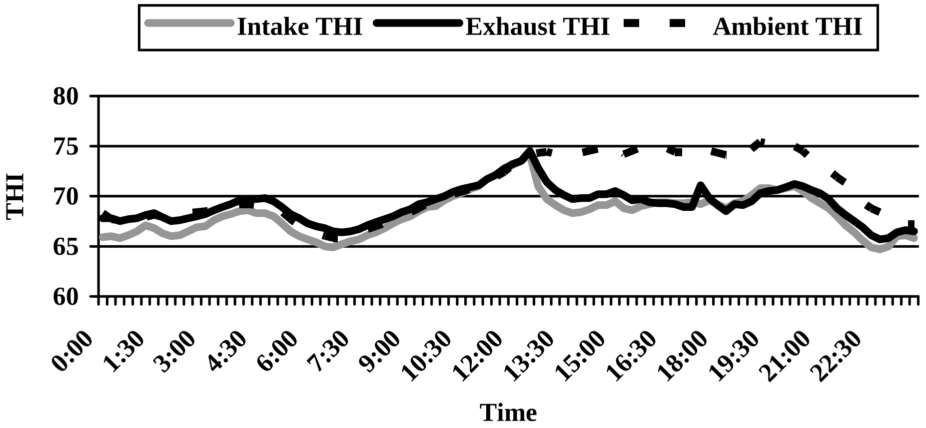

Figure 10: Average Day, THI (7-1-06)

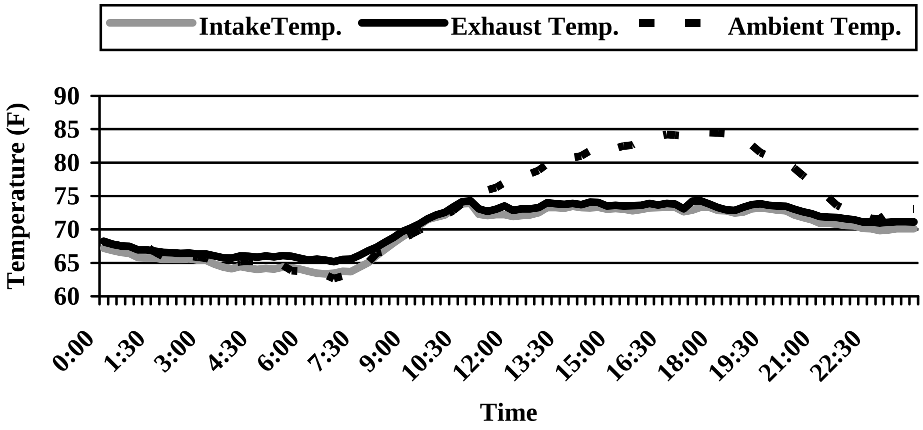

Figure 11: Humid Day Temperature (7-26-06)

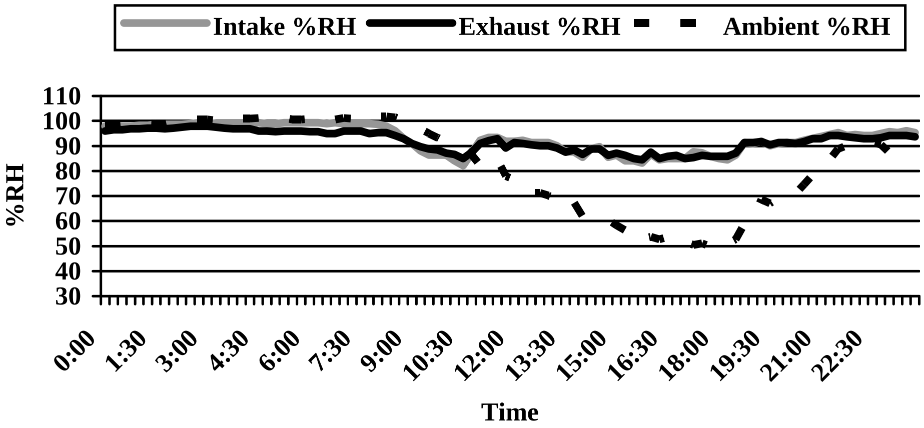

Figure 12: Humid Day Relative Humidity, % RH (7-26-06)

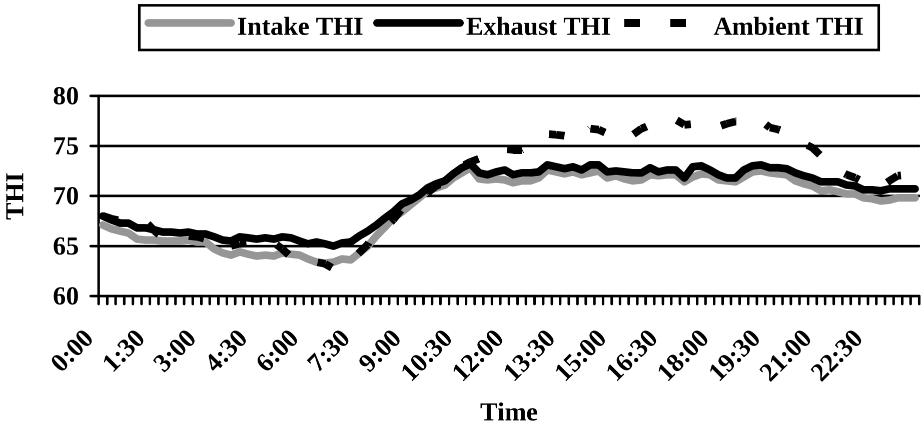

Figure 13: Humid Day, THI (7-26-06)

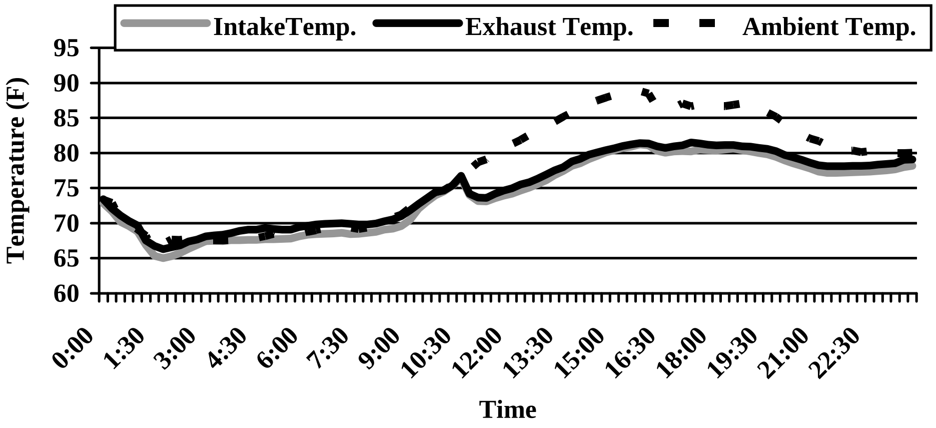

Figure 14: Very Humid Day Temperature (7-29-06)

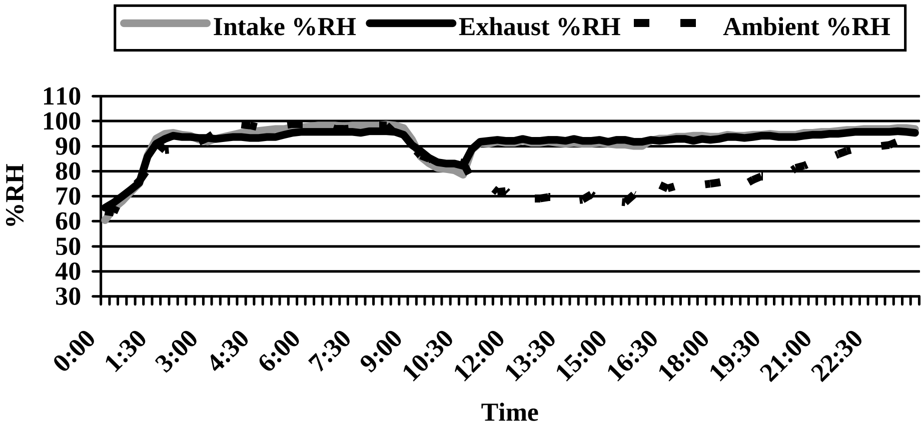

Figure 15: Very Humid Day, %RH (7-29-06)

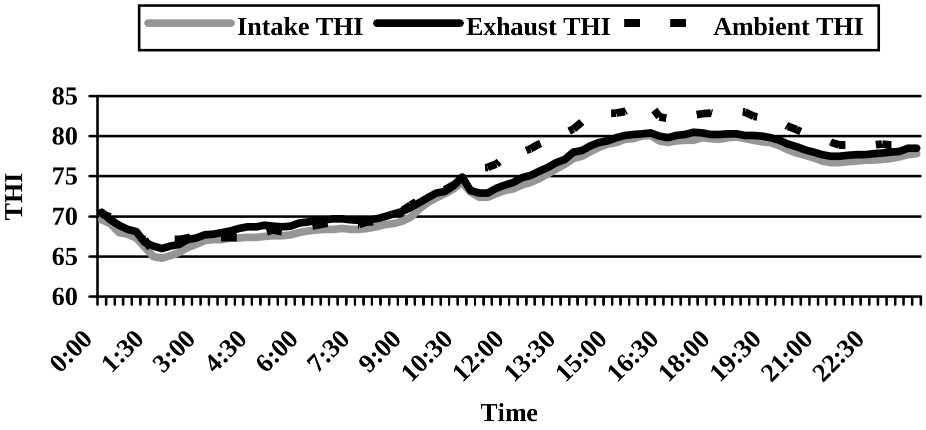

Figure 16: Very Humid Day, THI (7-29-06)

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.

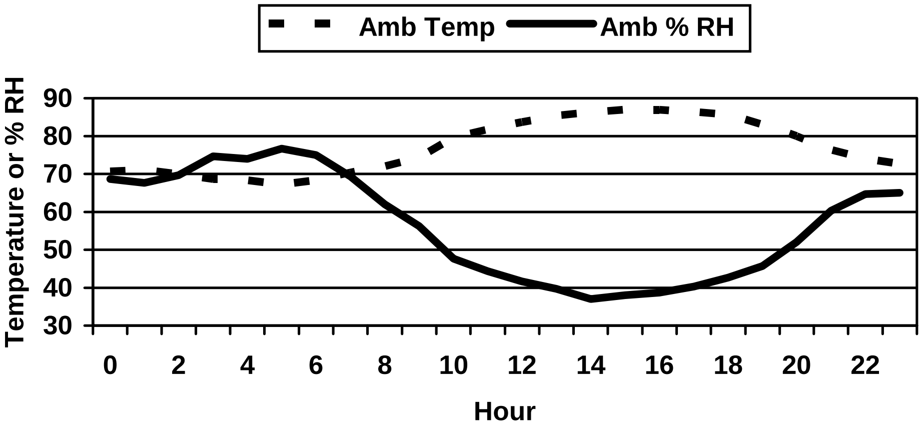

Figure 17: Ambient Temperature and % RH for Milnor, ND (July 6-9, 2006)

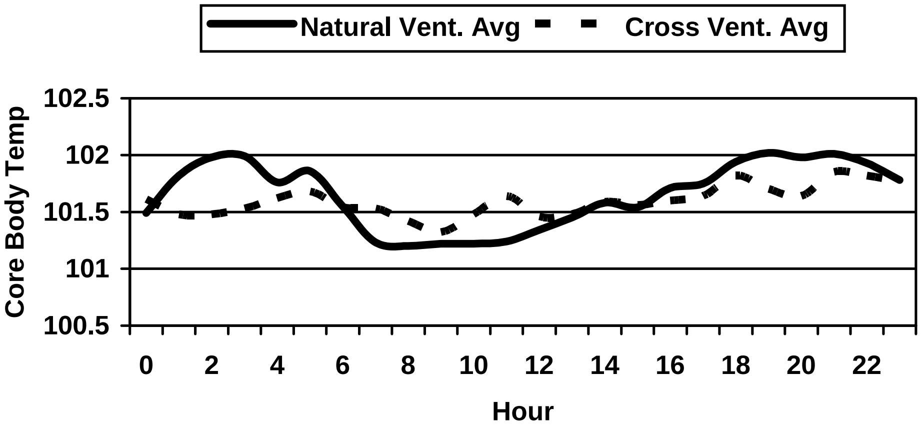

Figure 18: Core Body Temperature of Cows Housed in Naturally Ventilated (Fans & Soakers) and LPVC Freestalls (Evaporative Pads)

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).

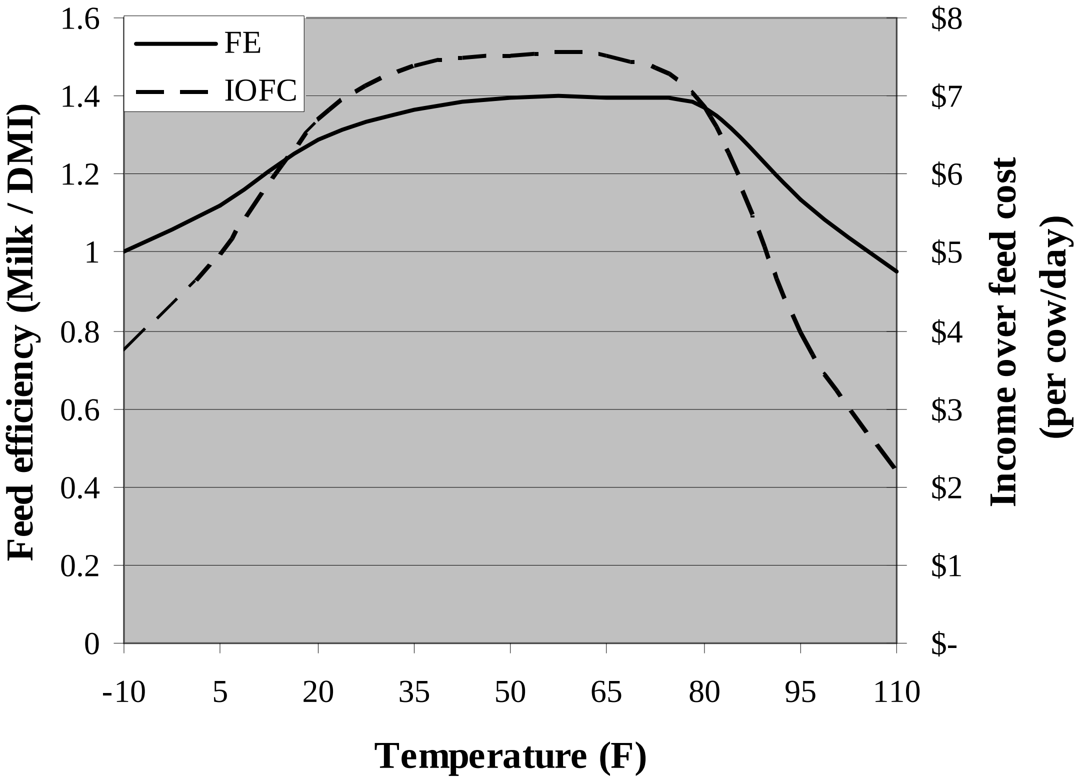

Figure 19: Responses to Environmental Stress, (Thermoneutral Production of 80 lbs/day, TMR Cost of $0.12/lb Dry Matter, and Milk Value of $18/cwt)

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° 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° 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	Conception 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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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° F temperature rise across the building per 100 feet of building width.
- The average building temperature is 20° 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.

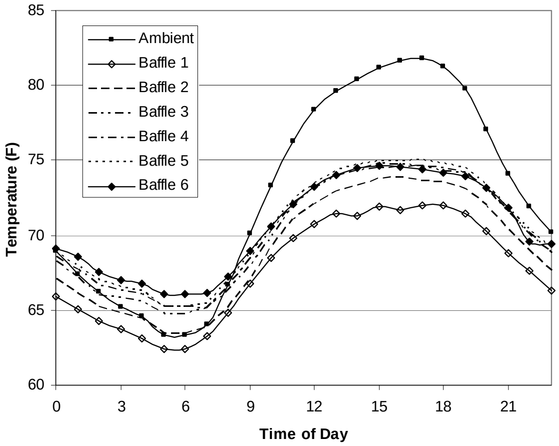

Figure 1: Average Temperature at Different Baffles in an LPCV Building from July 17 to August 16, 2007

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.

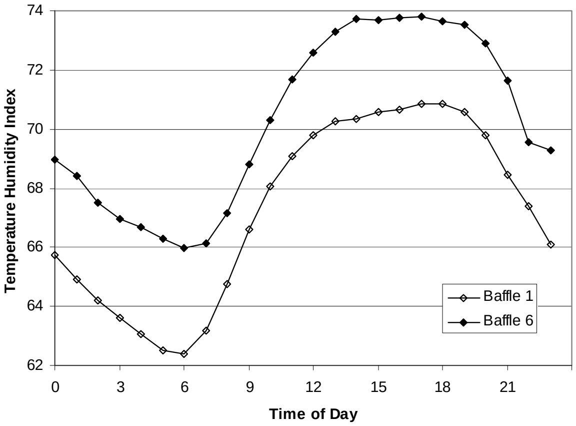

Figure 2: THI at the First and Last Baffle in an LPCV Building During the Summer of 2007

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° F if ambient conditions are 86° F and 62% humidity. The average temperature drop across the evaporative cooling system was approximately 8-10° F

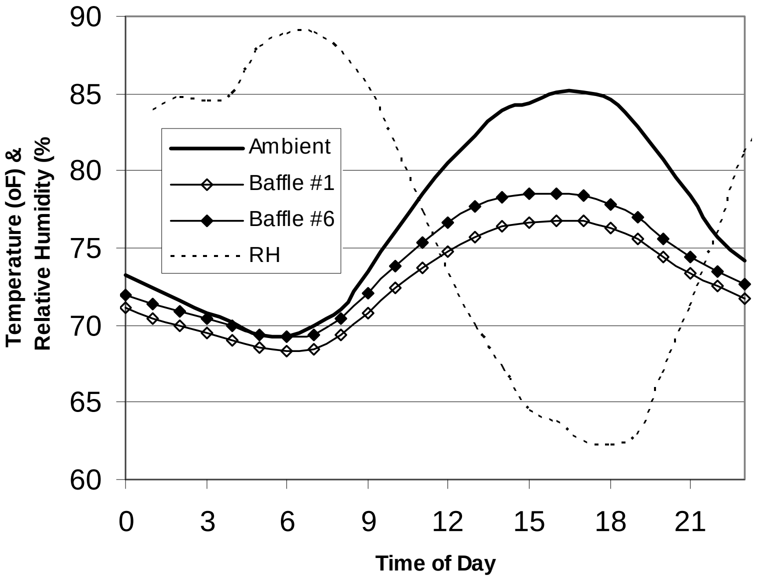

Figure 3: Average Ambient Temperature, Relative Humidity and Temperatures at the First and Last Baffles in an LPCV Building During the Summer of 2007

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 °F, and the average temperature rise across the buildings is 0.0092 °F per foot of building width. Approximately 1° 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 (°F) Between Baffles***	**Average Temperature (°F) Rise/Foot of Building Width***
# 1	0.65 °F	0.0085 °F/ft
# 2	0.51 °F	0.0077 °F/ft
# 3	0.62 °F	0.0110 °F/ft
# 4	0.47 °F	0.0095 °F/ft
Average	0.58 °F	0.0092 °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.

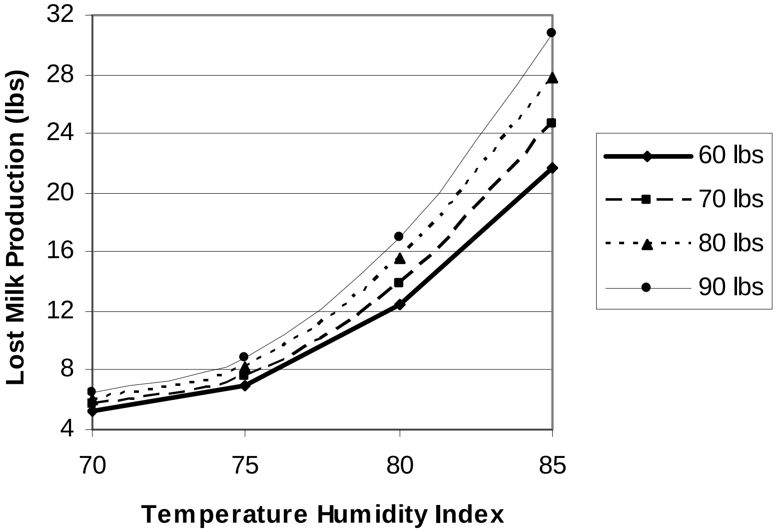

Figure 4: THI and Milk Production Loss for Cows Milking 70, 80 and 90 lbs (based on the equation by Berry et al (1964))

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.

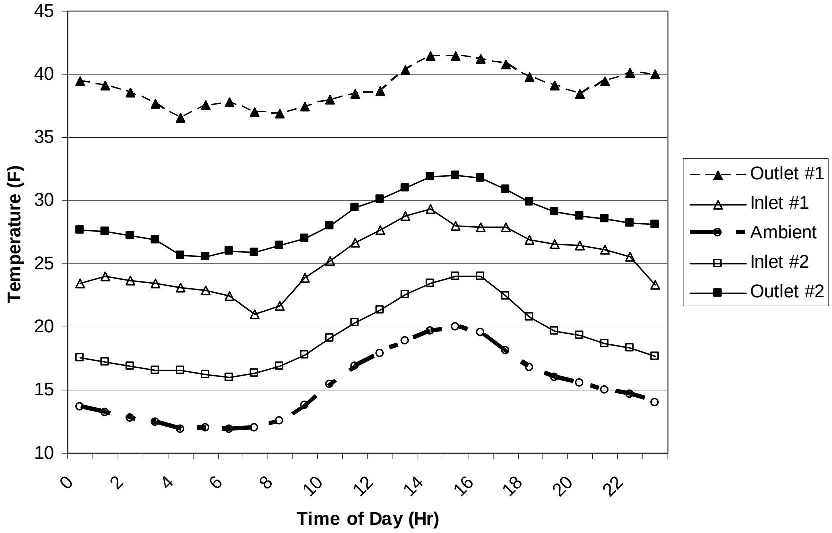

Figure 5: Summaries of Temperatures From Jan.18 to Feb.17, 2008, for 2 400-ft wide LPCV Buildings in Iowa

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° F when the inlet air temperature is -5° 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.

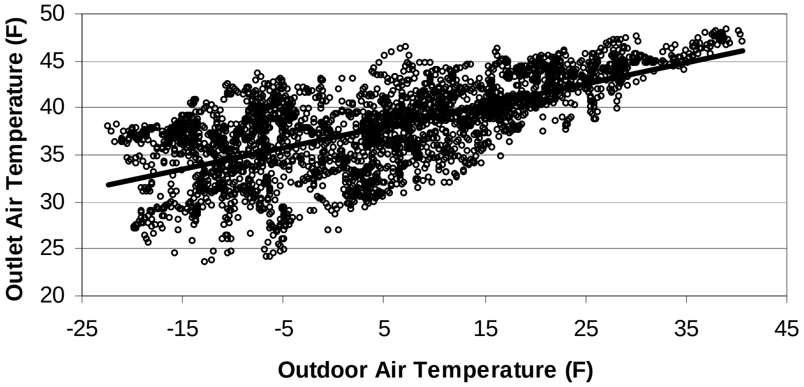

Figure 6: Outdoor Air Temperatures and Outlet Air Temperatures in an LPCV Building During the Winter of 2008

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 °F since there are more consistent strategies in fan operation and less concern about freezing alleys.

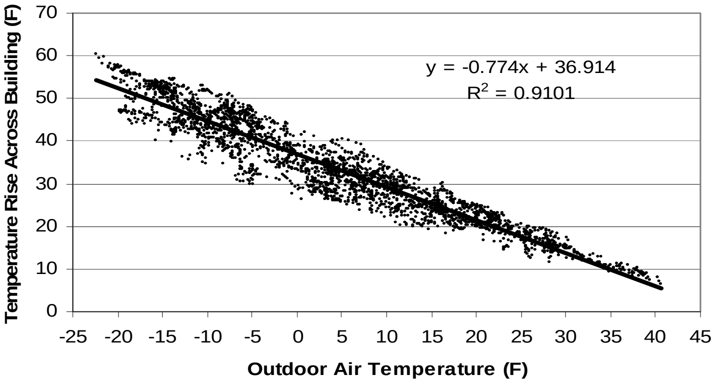

Figure 7: Outdoor Air Temperature and Temperature Rise Across a 500-foot wide LPCV Building in Minnesota During the Winter of 2008

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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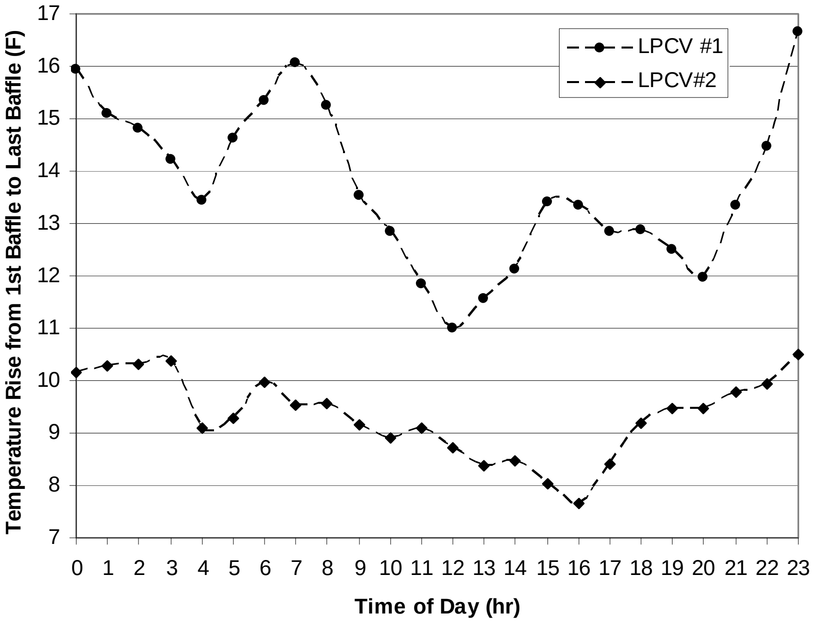

Figure 8: Temperature Rise from the First to Last Baffle in 400-foot wide LPCV Buildings in the Winter of 2008 in Iowa

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.

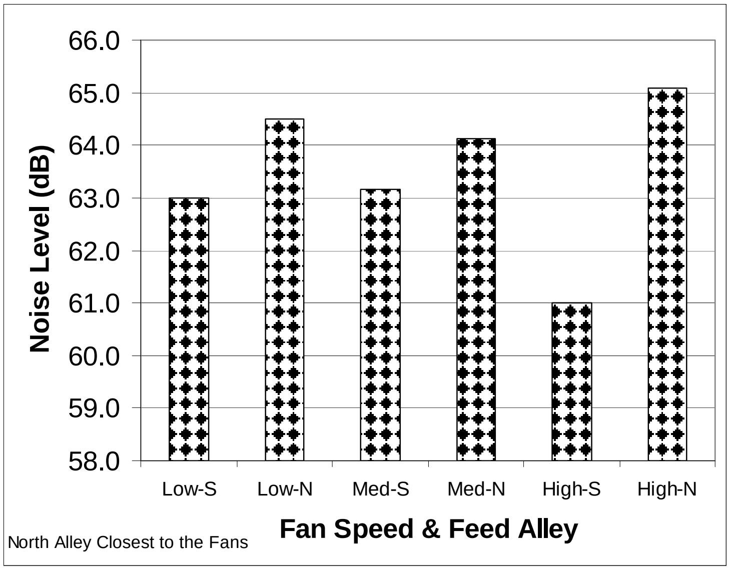

Figure 9: Noise Level Based on Fan Speed and Feed Alley

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.

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Fans: Airflow versus Static Pressure

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J. P. Harner and J. F. Smith, Kansas State University
S. Pohl, South Dakota State University

TAKE HOME MESSAGES

- Fans of the same diameter are not all created equal. Airflow capacity at different static pressures varies depending upon fan make and model.
- Increasing the static pressure a fan must operate against reduces the amount of airflow delivered by fan.
- Use fan performance data to select fans for the specific application and situation.

INTRODUCTION

All ventilation systems have five functional components: an inlet, an outlet, a driving force, distribution and a path. 1) The inlet provides a location or locations for air to enter the cow space. 2) The outlet provides the location for air to leave the cow space. 3) The driving force provides the means to move air into, through, and out of the cow space. 4) Distribution defines how air moves through the cow space. 5) The path must exist so that air can enter the facility, go through the inlet, pass through the cow space, leave through the outlet, and finally exit the facility. If all five functional components exist and are operating properly, the ventilation system probably is working for the given weather and animal stocking conditions. Solutions to most ventilation problems are found by identifying which functional component(s) is missing or improperly operating.

LPCV COMPONENTS

Fans serve as the outlet and driving force in the mechanical ventilation systems in LPCV dairy barns. The inlets are often an evaporative cooling pad or some other inlet components. Distribution is created by the placement of the inlets. Air in an LPCV facility follows a path from the outside, through the inlet evaporative cool cell or other inlet components, under/below various baffles and, finally, out the fans. Understanding the path air takes and how the path interacts with the driving force helps ensure a well-designed and fully-operating LPCV dairy barn ventilation system.

STATIC PRESSURE

Static pressure is used to evaluate the amount of impact various ventilation system components have on the airflow path within a given system. For mechanical ventilation systems, the fans create positive static pressure to move air through a given system. All other components create negative static pressure that causes resistance to air moving through a system. A mechanical ventilation system operates with the static pressure in balance. The positive static pressure created by the fans equals the negative static pressure created by resistance as air navigates obstacles in the ventilation path.

The unit of measure for static pressure is often inches of water (in. water). The static pressure of one inch of water is the suction needed to draw water up a straw one inch. For comparison, 1 pound per square inch static pressure (1 psi) is equal to 27.7 in. water static pressure. Sometimes static pressure is given as Pascals (Pa). The static pressure of 0.1 inches of water (in. water) is equal to about 25 Pascals (Pa).

FAN PERFORMANCE

Fans act as “air pumps” to move air via the path through a building. Fan designs include different fan blade pitches, distinct number of blades per fan, various operating speeds, and required or provided input motor horsepower. Additional sources can be reviewed to learn more about fan types and design (MWPS-32, 1990).

Most agricultural ventilation fans operate at 0.05 to 0.15 in. water static pressure and deliver a given airflow rate in cubic feet per minute (cfm) at a particular static pressure. Some agricultural ventilation fans can effectively operate at static pressures of up to 0.25 in. water by delivering a cfm airflow rate similar to the cfm rate at much lower static pressures. The performance of a fan is defined as the amount of airflow in cfm at a given static pressure. The performance of agricultural ventilation fans is tested and reported by the BESS Lab at University of Illinois. The performance and efficiency test results for agricultural ventilation fans can be found at http://www.bess.uiuc.edu/. Table 1 shows some example test results for various large diameter fans.

VENTILATION DESIGN

A ventilation system should be designed by matching the available static pressure of an agricultural ventilation fan with the estimated static pressure resistance caused by components in the ventilation path. In an LPCV barn, the airflow rate of an exhaust fan and the static pressure must equal the total sum of the resistances caused by the inlet system (inlets and evaporative cooling pad), plus the resistance caused by baffles in the barn. If the estimated static pressure resistance is greater than the available static pressure of the fan, the airflow cfm delivered by the fan decreases until the system pressures match. A matching of the system occurs when the airflow delivered by the fan at a given static pressure equals the static pressure resistance of the components in the path at the airflow cfm rate delivered by the fan.

SUMMARY

Fan performance varies amongst different makes, models and manufacturers. Information is available from the BESS lab on performance of different fans. Fan performance decreases as the static pressure increases.

REFERENCES

BESS Lab. Agricultural Ventilation Fans, Performance and Efficiencies. Bioenvironmental and Structural Systems Laboratory. Department of Agricultural Engineering, University of Illinois. Urbana-Champaign, IL. (www.bess.uiuc.edu)

MWPS-32. 1990. Mechanical Ventilating Systems for Livestock Housing. Midwest Plan Service, Iowa State University, Ames.

Table 1: Fan Performance Data for Various Large Diameter Fans Using Single Phase Motors

Fan		Motor Size (hp)		Airflow (cfm) at Various Static Pressures (in. water)						
Size	Make		Test #	0.00	0.05	0.10	0.15	0.20	0.25	0.30
48	Acme	1.0	07208	23800	22900	21900	20600	19200	17600	15700
48	Hired Hand	1.0	98197	26900	25700	24200	22600	20900	18900	16100
48	Aerotech	1.0	98030	25000	23500	21800	19900	17600	13800	9500
54	Airstream	1.5	06218	na	30800[1]	29500	26800	23900	20600	16500
54	Hired Hand	1.5	08154	28700	27400	25800	24200	22200	19800	17200
54	Aerotech	1.0	06141	29500	27800	26000	23900	21300	18200	12200
55	Aerotech	1.5	06129	30800	28900	27000	24500	21200	16900	8100
55	Aerotech	2.0	06145	na	na	na	31200[2]	28900	25700	21700

na – test results are not available because capacity exceeded test chamber equipment.

[1] – Test result actually for a static pressure of 0.07 in. water

[2] – Test result actually for a static pressure of 0.16 in. water.

Note: Above performance data examples are from all available fan performance data reports from BESS Lab website (http://www.bess.uiuc.edu/) accessed on August 20, 2008. The distribution of reports is as follows:

- 48” fans using 1 phase 230V, 60 Hz - 167 fan performance test reports
- 48” fans using 3 phase 230V, 60 Hz - 74 fan performance test reports
- 54” fans using 1 phase 230V, 60 Hz - 53 fan performance test reports
- 54” fans using 3 phase 230V, 60 Hz - 38 fan performance test reports
- 55” fans using 1 phase 230V, 60 Hz - 4 fan performance test reports
- 55” fans using 3 phase 230V, 60 Hz - 4 fan performance test reports

“Let it Flow, Let it Flow”
Moving Air into the Freestall Space

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TAKE HOME MESSAGES

- Baffles allow cool, upper air to mix with warmer air in the lower part of a building.
- Total static pressure drop across a building should be limited to 0.15 inches for optimum fan performance and ventilation.
- The Pitot tube equation may be used to estimate the air velocity beneath a baffle once the static pressure is known.
- A minimum recommended baffle opening is 7 to 8 feet above the freestall curb to minimize equipment and animal damage.
- The baffle opening must be designed based on sidewall inlet area, inlet air speed and static pressure

INTRODUCTION

Research shows that 12 to 14 hours of rest per day are the minimum requirements for dairy cows to maintain optimum performance. In order to achieve this desired rest, a cow’s freestall must be a comfortable size and temperature. Naturally ventilated freestalls use fans to provide air movement in the stalls to ensure they remain comfortable, even during heat stress. Low profile cross ventilated (LPCV) buildings use equivalent fan power to move air across the entire building, rather than blow air directly into individual stalls. The challenge in LPCV buildings is maintaining a proper balance between the cow comfort, fan performance and turbulence created by the moving air.

BAFFLES

Baffles are located over stalls in LPCV facilities to increase air velocity in each freestall area. Air movement beneath a baffle causes air streams from the upper and lower portions of the building to mix and create turbulence. Turbulent flow results when air encounters an obstacle and is diverted in another direction. As a result, cooler air near the roof is forced to move under the baffle and mix with warmer air streams in the cow space, thus avoiding laminar air flow. Laminar flow occurs when the air stream moves straight across the building rather than mixing with adjacent air streams. Because air entering a side wall at 5 miles per hour (mph), will typically exit a 400-foot wide building in less than 2 minutes, there is minimum time for the mixing of air streams unless turbulence is created by a baffle. In addition, an increase in velocity of the air beneath the baffle results in a proportional increase in static pressure which must be overcome by fans.

ENERGY

Fluid mechanics describes fluids, including air, as possessing three different forms of energy that are not based on temperature: pressure, kinetic and potential. Pressure energy is often called pressure head, or static head, and is typically measured by a pressure gauge. For airflow and ventilation applications, a static pressure difference is measured. If a static pressure difference, or difference in pressure head, is observed, the pressure energy differs from one location to the other. Kinetic energy is associated with the movement of a fluid. It is required to accelerate a fluid and is quantified by the velocity of the fluid at a given location. When kinetic energy is added to the air, air velocity increases. The third form of fluid energy is potential energy. Potential energy for fluids is often called gravitational head, or potential head. Potential head is measured by the elevation of the fluid above a defined reference point. A fluid that is located at a high elevation has a greater potential head than a fluid located at a lower elevation.

AIR DEFLECTION BAFFLE TEST

The static pressure and velocity observations of an air deflection baffle are related to the previous fluid mechanics discussion. A static pressure difference was measured from one side of an air deflection baffle to the other, which means that the pressure energy on the inlet side of the baffle was greater than the pressure energy on the exhaust side. Since pressure energy was lost, the lost energy must be found in another type of fluid energy. No difference in elevation existed from one side of the baffle to the other, so no change in potential energy existed. The air stream continued to move through the building, so all the pressure energy differences, as indicated by the measured static pressure differences, was not lost. The baffle caused pressure energy to be converted into kinetic energy because the velocity of the air stream was accelerated from the inlet side of the baffle to the exhaust side. The conversion of the pressure energy to kinetic energy along with some possible losses at the baffle, resulted in the fluid energy being conserved as the air moved from the inlet side of the air deflection baffle to the other side.

BERNOULLI EQUATION

The Bernoulli equation (Henderson and Perry, 1976) from fluid mechanics states that the energy of a fluid at point A must be equal to the energy of the same fluid at point B unless energy loss occurs between the two points, or unless energy is added to the fluid by some other method. Therefore, the Bernoulli equation is the sum of all energies at point A (pressure, kinetic, and potential), plus any energy additions that total the sum of all energies at point B, minus any fluid energy loss from point A to point B. In essence, all the energy in a fluid, or air, moving from point A to point B can be determined and conserved.

The Bernoulli equation can also be used to quantify the static pressure from a fan in a low profile cross ventilated freestall barn. Air moves from outside (point A), through the cool cell pads, under each baffle, and exits the fan to the outside (point B). The fan actually adds pump energy to the energy balance defined by the Bernoulli equation. The increase in air velocity under a baffle is lost because of the air mixing from one baffle to the next. Therefore, the static pressure differences observed at each baffle must add together to estimate the total static pressure, or pressure energy, the exhaust fans must add to the ventilation air stream.

FAN PERFORMANCE

An exhaust ventilation fan delivers different ventilation rates depending upon the static pressure against which the fan is operating. A fan delivers its maximum airflow rate when no static pressure differential is placed against the fan. As the static pressure difference increases, the delivered airflow rate decreases and adds additional stress on the fan, decreasing performance and the length of fan life. The static pressure difference may increase enough to result in the fan being unable to move any air.

The relationship between the operating static pressure and the delivered ventilation rate is called the fan curve, or fan performance curve. The fan curve and maximum operating static pressure are specific to each fan make and model. The static pressure resistance caused by a baffle system and/or air inlet system must be less than this maximum operating static pressure or no air will be ventilated from the facility.

Each baffle in an LPCV facility causes a static pressure difference the fan(s) must overcome to achieve adequate ventilation. Increasing the number of baffles in a facility results in a larger overall static pressure differential. If together the installed fans cannot provide the desired ventilation rate with the resulting static pressure difference created by the baffles, no individual fan is able to deliver adequate ventilation. A balance for the total ventilation system is found when the static pressure differential created by a series of baffles is matched by the fan-operating static pressure differential and the ventilation rate delivered by any given fan. Lower total static pressure generally results in higher delivered ventilation rates for a total ventilation system. On the other hand, higher total static pressure differentials often result in lower delivered ventilation rates.

STATIC PRESSURE

The static pressure against which an exhaust fan must operate is significant when the air velocity is at its highest for summer ventilation rates, as shown in Table 1. The presence of cows in the pen impacts the static pressure. Results of static pressure at the first baffle were as follows: when no cows were in the pen, pressure was 0.025 inches; when cows were locked in headlocks, the pressure measurement was 0.031 inches; when cows were present in the pen, static pressure was 0.029 inches. Static pressure at the second baffle when no cows were present was 0.033 inches, and the measurement increased to 0.037 inches when cows were locked in headlocks. A "buffer adjustment" should be added to the theoretical static pressure estimate for a no-cow, empty-barn scenario.

Table 1: Air Velocity and Static Pressure across an LPCV Barn

		Static Pressure (in H_2O)				
Structural Bay	**Velocity (ft/min)**	**First Baffle[1]**	**Second Baffle**	**Third Baffle**	**Fourth Baffle[2]**	**Comments**
1			0.033	0.026	0.029	West end cross alley
2	547	0.240	0.032	0.028	0.036	
3	525	0.025	0.032	0.027	0.035	
4	560	0.025	0.036	0.026	0.037	
5	580	0.025	0.034	0.027	0.036	Crossover
6	560	0.025	0.028	0.029	0.034	
7	530	0.026	0.032	0.028	0.036	
8	560	0.026	0.033	0.026	0.038	
9	550	0.025	0.038	0.029	0.040	Crossover
10	590	0.026	0.035	0.028	0.035	
11	600	0.023	0.036	0.028	0.036	
12	560	0.026	0.034	0.030	0.034	
13			0.030	0.025	0.041	East end cross alley
14			0.032	0.034	0.032	Palor cross alley
		No cows	No cows	With cows	With cows	Cows in pen when data collected?

[1] = Baffle adjacent to air inlet.

[2] = Baffle adjacent to ventilation fans.

The distribution of cows within the pen also has an impact on the static pressure. The fourth baffle appears to have average static pressure measurements, but the distribution of the static pressure difference is a bit more pronounced. For example, due to a maintenance problem on the farm, cows crowded around the crossover alleys during the third replication at the fourth baffle and created a visible static pressure difference. This variation is directly proportional to the air speed under the baffle because if cows crowd together, less air is able to move through the group.

Overall dairy management must be designed to minimize the opportunities for cows to bunch together, and, therefore, increase static pressure. Stressful situations for cows often result in a herding instinct, even though the resulting cow grouping may actually increase the stress level and reduce ventilation in the facility. The current design practice recommends limiting the total static pressure drop to 0.15 inches.

HELPFUL EQUATIONS

The total static pressure is the sum of the pressure drop across the sidewall inlet and each baffle. The Pitot tube static pressure equation may be used to help design the baffle opening. The equation used to calculate the velocity of Pitot tube (Henderson and Perry, 1976) is:

$$V = 18.3(SP_{\text{pitot tube}} / SW)^{\wedge 0.5} \qquad \text{eq 1}$$

Where:

$SP_{\text{pitot tube}}$ is the static pressure drop (inches of water)

V is the velocity of air in feet per second

SW is the specific weight of the air in pounds per cubic foot.

A simple way to calculate the static pressure drop per baffle is to use the following equation:

$$SP_{\text{baffle}} = (SP_{\text{total}} - Sp_{\text{inlet}}) / \text{ Baffles} \qquad \text{eq 2}$$

Where:

SP_{baffle} is an estimate of the static pressure drop across each baffle

SP_{total} is the total static pressure drop (equal to 0.15)

Sp_{inlet} is the static pressure drop across the sidewall inlet (assume equal to 0.05)

Baffles is the number of baffles.

The air velocity (fps) beneath a baffle is then calculated using equation 1 or equation 3 and may be used to estimate the air velocity (in feet per minute) beneath the baffles.

$$\text{Baffle}_{\text{airflow}} = 4{,}000 \times (SP_{\text{baffle}})^{\wedge 0.5} \qquad \text{eq 3}$$

Where:

$\text{Baffle}_{\text{airflow}}$ is the average air velocity under the baffle in feet per minute.

Finally, the height of the baffle opening in each freestall is found by using

$$\text{Baffle Opening} = \text{Airflow per Foot} / \text{Baffle}_{\text{airflow}}$$

Where:

Baffle Opening is the bottom height of the baffle above the freestall curb (measured in feet)

Airflow per Foot is the total inlet airflow per foot of building.

BAFFLE DATA

Figure 1 shows the influence of air speed on baffle openings for a given number of baffles. Baffle openings less than 72 to 84 inches above the curb are impractical and can result in cow interference and equipment damage. Figure 1 shows a minimum of 4 baffles are recommended when the inlet air speed is 400 feet per minute (fpm) or less. Generally, LPCV facilities are designed with one baffle for every two rows of freestalls to provide adequate ventilation.

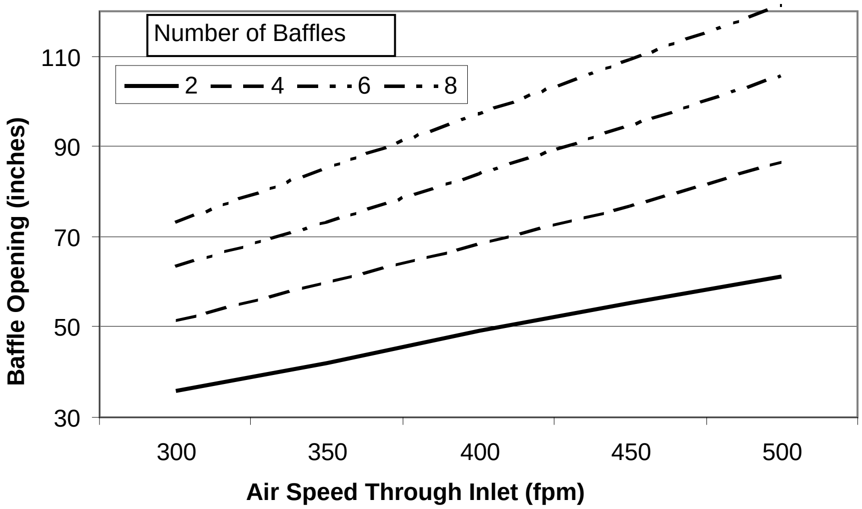

Figure 1: Impact of Air Speed on Baffle Openings and Number of Baffles

Figure 2 illustrates the average air speed beneath a baffle. An air speed of 5 to 6 mph in the freestall area is usually recommended to promote stall usage and improve cow comfort during heat stress periods. Dairy cows begin to exhibit heat stress when ambient temperatures exceed 70 ^oF. Air speed in the stall area may be reduced when the environmental temperature decreases.

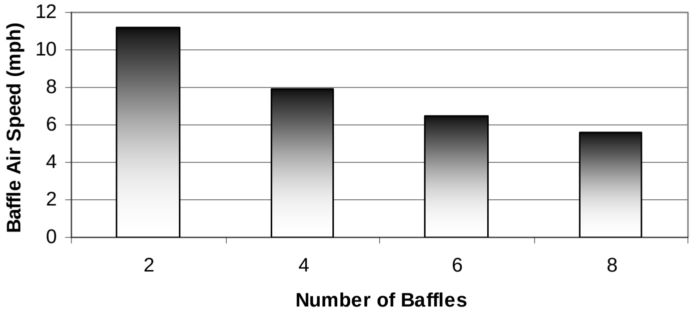

Figure 2: Influence of Number of Baffles on Baffle Air Speed with Limited Static Pressure Drop to 0.1 Inches

SUMMARY

Baffles allow mixing of air streams inside a building and increase the air velocity in the freestall area. An excessive static pressure drop reduces the efficiency of a fan. Proper baffle design limits the total static pressure drops across the inlet and baffles to 0.15 inches of water or less. Baffle openings must also accommodate equipment operating in cross alleys. Animals should not be able to damage the bottom of a baffle if placed 7 to 8 feet above concrete floors.

REFERENCES

Henderson, S.M. and R. L. Perry. 1976. Agricultural process engineering. The AVI Publishing Company, Inc. Westport. Co. pp 9-59.

Cooling Inlet Air in Low Profile Cross Ventilated Freestall Facilities

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TAKE HOME MESSAGES

- Evaporative cooling is effective in lowering the ambient air temperature of a low profile cross ventilated freestall building.
- In the Upper Midwest where the relative humidity tends to be above 50%, air temperatures inside an LPCV building are consistently 8 to 15 ^{o}F cooler than the ambient temperatures after evaporative cooling. The temperature differential is a function of relative humidity.
- Evaporative pads and high-pressure mist systems are two commons systems for cooling incoming air in a low profile cross ventilated freestall building.

INTRODUCTION

Cooling the air inside a low profile cross ventilated facility requires the consideration of several factors. Outdoor air temperature, relative humidity, and the evaporative cooling system all affect the indoor temperature of the buildings.

Because air temperature decreases and humidity increases as moisture is added to the air, the lowest temperature occurs when the air is at 100% humidity, or saturation. If two air streams are at the same temperature but have different relative humidity levels, the stream with less humidity is able to be cooled to a lower temperature than the stream with high humidity.

The air-water vapor properties of air provide a method to determine the temperature drop of an air stream after passing through an evaporative cooling system. The dry bulb temperature is the measurement of the air temperature with a thermometer or reported by a weather station. This temperature is measured with a dry wick, or bulb, on the thermometer. The wet bulb temperature may be calculated using the air-water vapor equations if the relative humidity is known. The wet bulb temperature is measured by placing a “wet” wick over the bulb of a thermometer. The dry and wet bulb temperatures are equal at 100% relative humidity, so if an evaporative cooling system is 100% efficient, then the dry and wet bulb temperatures are equal and the relative humidity is 100 percent. This state point provides an estimate of the maximum cooling potential of the air.

Figure 1 shows the wet bulb temperature for air at different dry bulb (ambient) temperatures and relative humidities. Cooling potential is the difference between the dry and wet bulb temperatures. If the temperature is equal, the cooling potential decreases as the relative humidity increases. The greatest cooling potential is observed at a higher air temperature and a lower humidity**.**

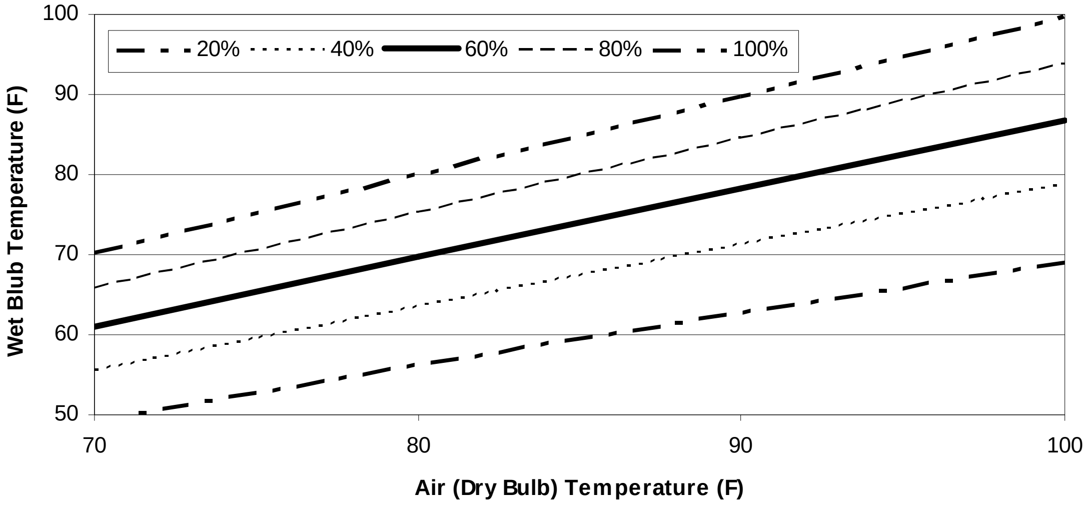

Figure 1: Impact of Air Temperature and Relative Humidity on Wet Bulb Temperature

The temperature humidity index (THI) is used as an indicator of heat stress. Cows begin to experience heat stress at a THI value of 70 and above. Figure 2 shows the THI values for different temperatures and relative humidity. The THI index exceeds 70 anytime air temperatures exceed 80 ^{o}F, irrespective of relative humidity. Relative humidity influences the THI index when temperatures are between 70 and 80 ^{o}F.

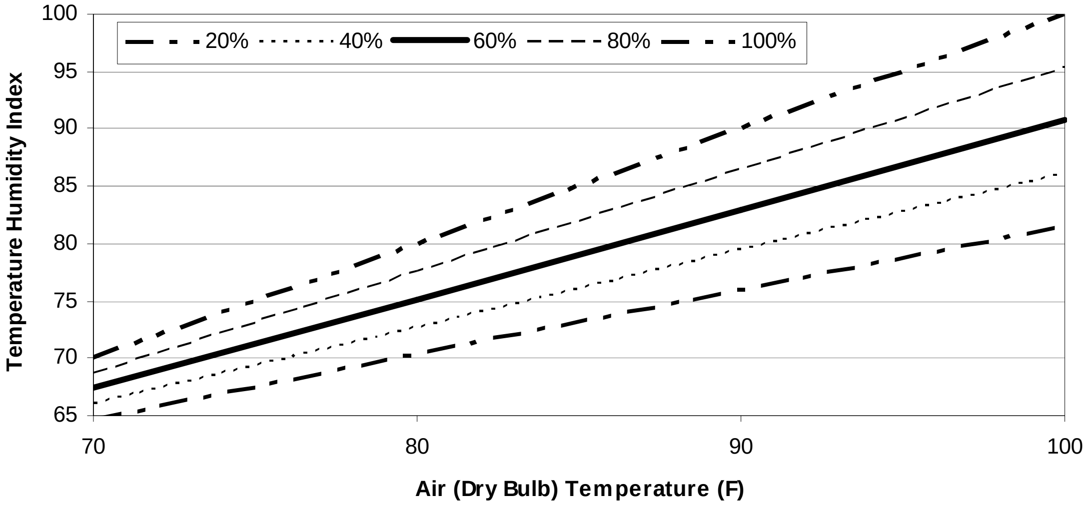

Figure 2: Impact of Air Temperature and Relative Humidity on Temperature Humidity Index

DATA FOR SIOUX FALLS, SOUTH DAKOTA

Figure 3 shows the temperature, relative humidity and temperature humidity index (THI) for Sioux Falls, SD on July 10, 2008. The relative humidity decreases during the afternoon hours as the temperature increases. Data shows that humidity levels are highest around 6:00 a.m. and lowest around 6:00 p.m., which means the temperature is lowest in the morning and highest during the late afternoon. The critical period for heat abatement and cooling cows is when the temperature humidity index is above 70. As Figure 3 shows, when the THI is above 70, the humidity is less than 70 %. As the THI increases, the humidity decreases. Figure 4 charts the weather in Sioux Falls, SD from July 10 to 16, 2008. Similar temperature-relative humidity patterns are observed throughout the week, as compared to data collected on one day in Figure 3.

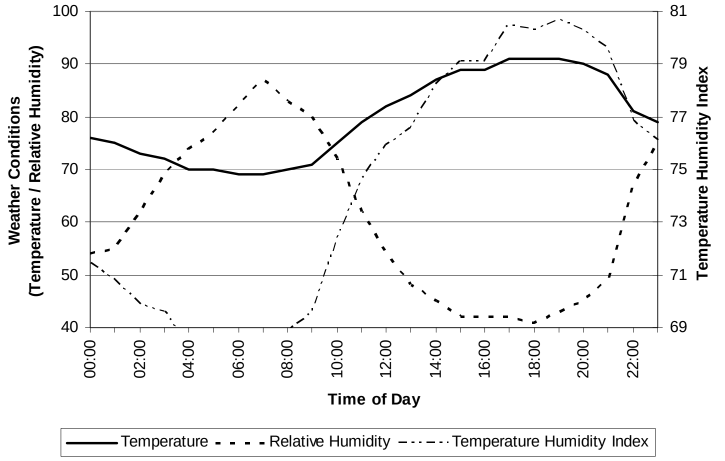

Figure 3: Weather Conditions for Sioux Falls, SD on July 10, 2008

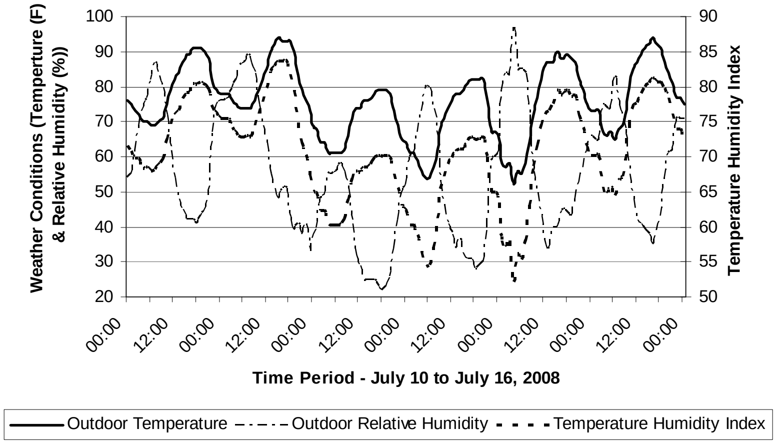

Figure 4: Weather Conditions for Sioux Falls, SD from July 10-16, 2008

Figure 5 plots the relative humidity and wet bulb temperature in comparison to the actual air temperature in Sioux Falls, SD for the week of July 10-16, 2008. The wet bulb temperature is defined as the potential temperature to which the air could be cooled, assuming a cooling system is 100% efficient, or creating 100% relative humidity level in the air. The trend line illustrates a decline in relative humidity as outdoor temperature increases.

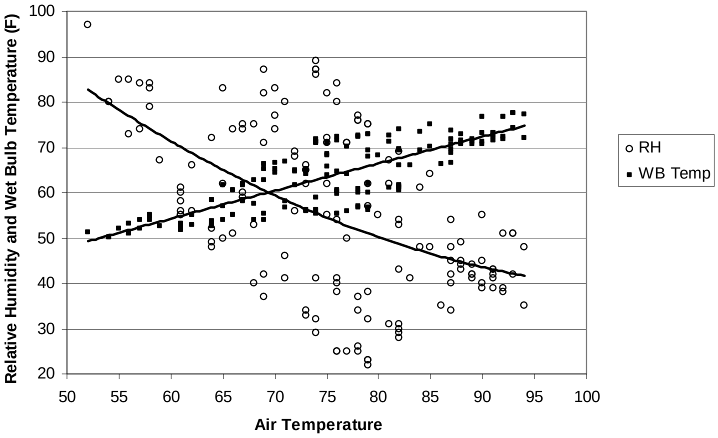

Figure 5: Relative Humidity, Wet Bulb Temperature, and Air Temperature from July 10-16, 2008, in Sioux Falls, SD

Figure 6 shows the potential temperature drops in Sioux Falls, SD that could occur, assuming 100% efficiency of a cooling system. The temperature drop varies at a given temperature because the relative humidity changes.

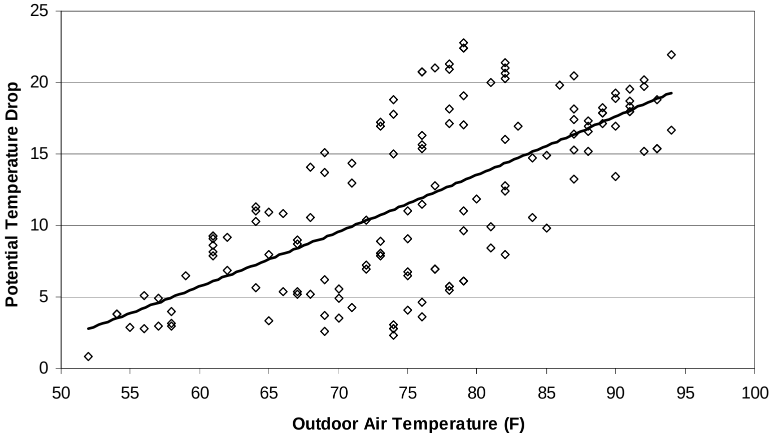

Figure 6: Potential Temperature Drops from July 10 -16, 2008, in Sioux Falls, SD

A comparison of minimum THI and outdoor THI is shown for Sioux Falls, SD in Figure 7. As the data demonstrates, the outdoor temperature humidity index is generally above 70 when the air temperature exceeds 72 ^{o}F. The minimum temperature humidity index occurs if the cooling system is 100% efficient. However, maintaining the environment at a THI of 70 or lower is possible even if the cooling system functions with less efficiency. The THI index should be below 72 anytime the outdoor air temperature is 85 ^{o}F or less.

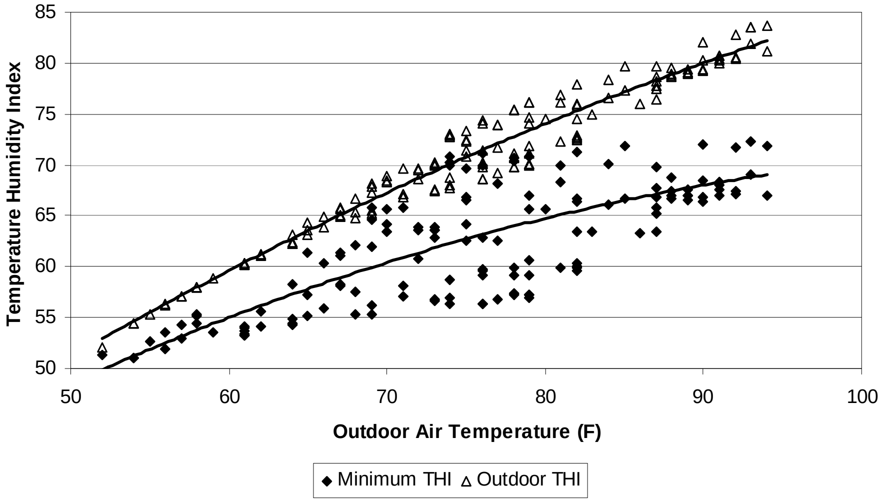

Figure 7: Minimum and Outdoor THI at Different Temperatures from July 10-16, 2008, in Sioux Falls, SD

COOLING SYSTEM FUNCTION

The cooling potential of any system is dependent upon the air's ability to absorb moisture. Lower relative humidity results in a lower air temperature inside the LPCV buildings. There are currently two systems used for cooling facilities: evaporative pad cooling and high-pressure mist systems. Evaporative cooling is currently the most common method for cooling LPCV buildings. Evaporative cooling results from warm air coming into contact with a high-pressure stream of moisture or a wetted surface, and the system is designed so no heat is added or lost from the air.

EVAPORATIVE PAD COOLING SYSTEM

The evaporative pad is a saturated cellulous material with channels that allow air to encounter moisture as it passes through the openings. Water is distributed along the top of the pad and flows down through the cellulous material, causing it to become saturated. Excess water at the bottom of the pipe is collected and recycled back to the top. Construction of evaporative pad cooling systems necessitates equal distribution of air through the pad and uniform temperature drops. Most evaporative cooling system designers assume the ideal air temperature is reached when the air absorbs 75 % of the available moisture. Figure 8 shows a graph of typical pad efficiencies for various face velocities and pad thickness. Manufacturers recommend limiting face velocity to 400 feet per minute (fpm). A 6 inch pad is commonly selected due to economics. The decrease in air temperature across an evaporative cooling system is a function of the relative humidity.

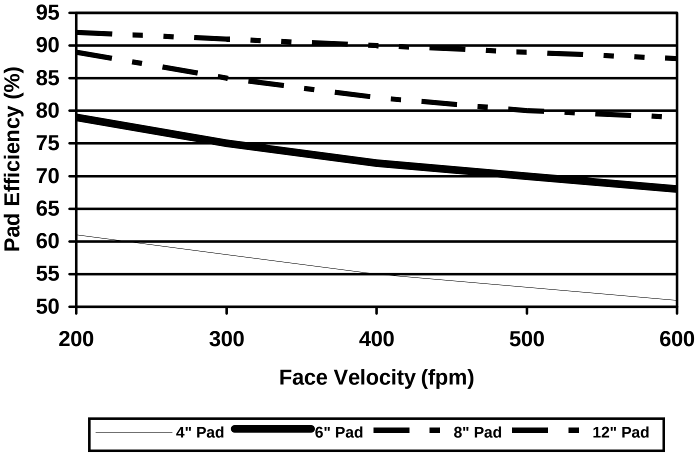

Figure 8: Impact of Face Velocity and Pad Thickness on Evaporative Pad Efficiencies (adapted from Anon, 2008).

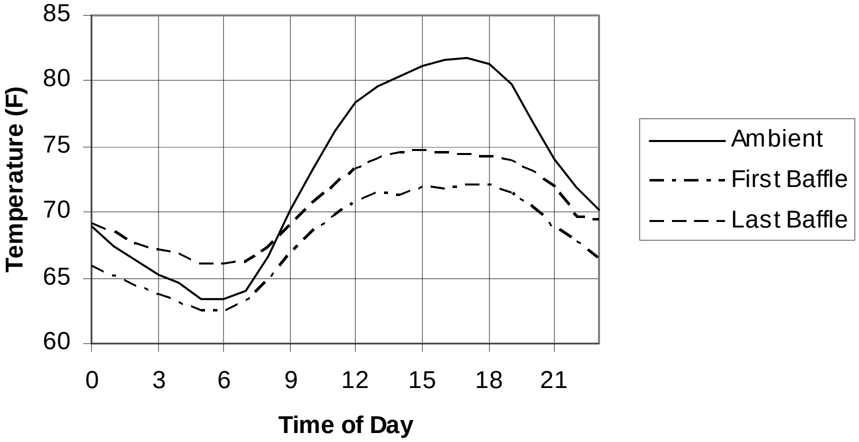

Figure 9: Impact of an Evaporative Cooling System on Air Temperature at the First and Last Baffle Over a 30-day Period

The hourly average temperature differences between the first baffle in an LPCV building and ambient air, as shown in Figure 9, illustrate the cooling potential of an evaporative pad. On average, the evaporative pad cools the air 8 to 13 ^{o}F during the afternoon hours. The cooling potential increases as the relative humidity decreases.

The performance of evaporative pads in LPCV facilities has been studied to determine water usage, changes in temperature, humidity, and THI. Water usage ranges from 0.3 to 0.4 gallons per hour per square foot of an evaporative pad area.

EVAPORATIVE PAD STUDY

Water usage per square foot of an evaporative pad for a dairy in Kansas was compared to a research dairy in North Dakota in the summer of 2006. As Figure 10 shows, similar water usage was observed between the Kansas dairy and the medium airflow rate at the North Dakota dairy.

Measured airflow rates were 320 feet per minute (fpm) through the pads at the Kansas site and 282 fpm in the medium airflow rate study. Water usage by the pad did not increase in proportion to the airflow rate. When comparing the high and medium airflow rates, the difference in air velocity was 47%. However, the increase in water usage of the evaporative pad was only 27% greater.

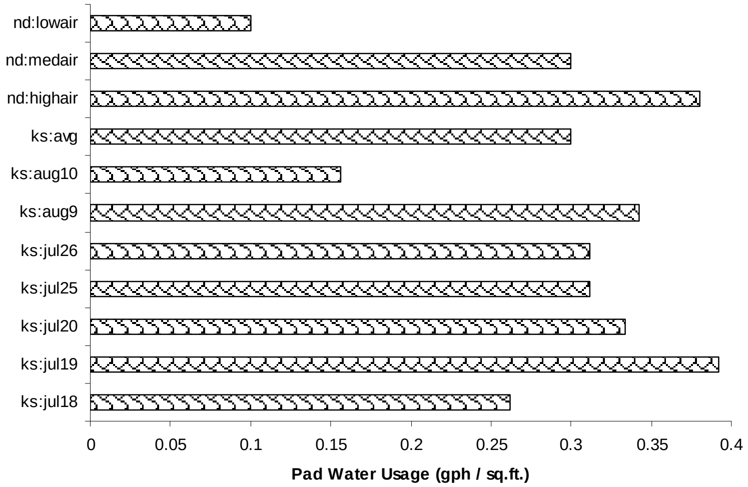

Figure 10: Evaporative Pad Water Usage at a Kansas (ks) and North Dakota (nd) Study Dairy (gph/sq.ft. = gallons per hour per square foot of evaporative pad surface)

At the North Dakota site, measured airflow rates through the pad averaged 106, 185, and 282 fpm for the low, medium, and high airflows, respectively. Per cow, water usage was 0.45, 1.37, and 1.75 gallons per hour while the evaporative pad was operating. Consumptive water use for each 15-minute period equaled 30.1 gallons for low airflow rate, 91.5 gallons for medium airflow rate, and 115.7 gallons for high airflow rate for a pad measuring 10 feet tall and 330 feet long.

HIGH-PRESSURE MIST SYSTEMS

High-pressure mist systems are an alternative to the evaporative pad cooling systems. The high-pressure mist system sprays fine droplets of water into the air stream, so the potential exists for non-uniform air temperature drops from the top to bottom along the sidewalls. This problem is 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 also allow an automated controller to determine the number of nozzles operating and the volume of water sprayed into the air stream based on ambient relative humidity. Water droplets that are not evaporated either drift and exhaust through the fans or fall to the floor. The controller conserves water by limiting the number of nozzles operating to the estimated water that may be absorbed by the air.

A typical nozzle of a high-pressure mist system has a flow rate of 0.03 gallons per minute (gpm) for a high-volume nozzle, or 1.8 gallons per hour (gph). At 75% efficiency, the actual water absorbed by the air equals 1.4 gph. Therefore, one high-pressure mist nozzle is equal to about four square feet of evaporative pad, assuming equal efficiencies. As a result, either a 10-foot evaporative pad or approximately 2 1/2 high pressure nozzles are required per running foot of building length, assuming equal performance.

The high-pressure system provides an open sidewall with a curtain-controlled inlet that operates from September to May. It allows some natural light to penetrate into the building which impacts the orientation requirement of the LPCV structure. One high-pressure mist distributor assumes the air temperature exiting the system equals the wet bulb temperature, minus 3 °F. At 100% relative humidity, the wet bulb temperature equals the dry bulb (ambient) temperature. These systems are being used in the southeast part of the United States in conventional tunnel ventilated freestalls, along with poultry houses.

The high-pressure mist system also requires an understanding of the aerodynamics of particles. Figure 11 shows the influence of air inlet velocity on exhaust time in an LPCV building. An increase in inlet velocity decreases the time required to move air from the inlet to the outlet, or exhaust fans. The horizontal lines show the time required for a 10, 30 and 100 micron water drop to fall 10 feet based on the terminal velocity of the droplet at a given size. A water droplet of 20 microns requires 254 seconds to fall 10 feet, while a 100 micron droplet requires 10 seconds.

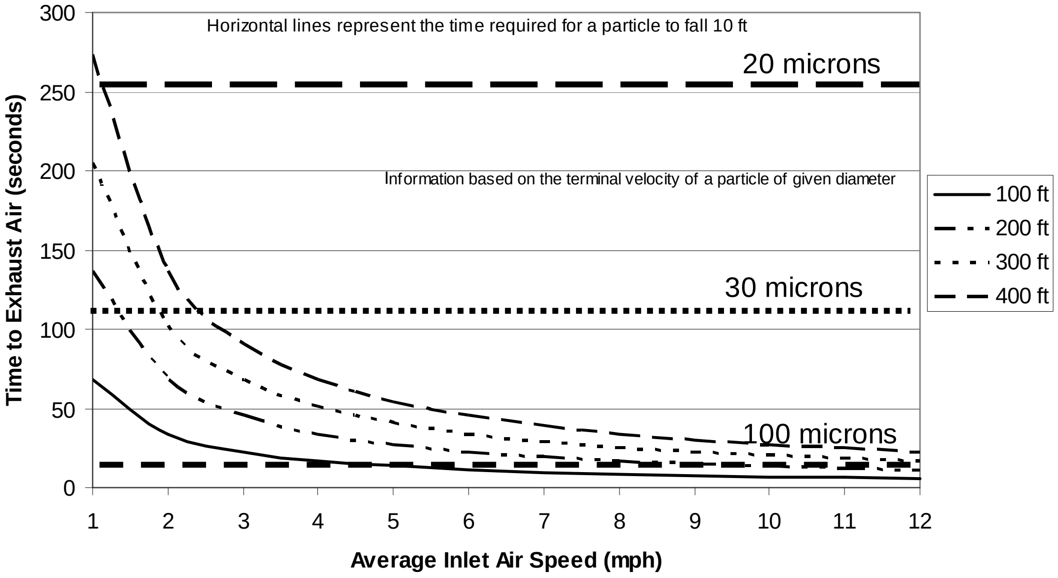

Figure 11: Influence of Inlet Speed, Exhaust Time, and Time Required for Different Size Particles to Fall

High-pressure nozzles create water droplets of 10 to 20 microns. Reducing the water pressure conserves water, but the water droplet size also increases. If the air inlet velocity is 3 miles per hour (mph), a 20 micron particle travels horizontally over 1,000 feet before falling 10 feet. Therefore, 10 to 20 micron particles tend to remain suspended in the air and be exhausted if not absorbed or evaporated.

Figure 12 shows the duration of a water droplet as a function of the droplet size for 0, 50 and 100% relative humidity at 68 °F (Hinds, 1999). As humidity or particle size increases, the droplet lifetime increases. A 20 micron diameter water droplet evaporates in approximately 1 second at

50% relative humidity. However, at 70% humidity, the same droplet takes 20 seconds to evaporate.

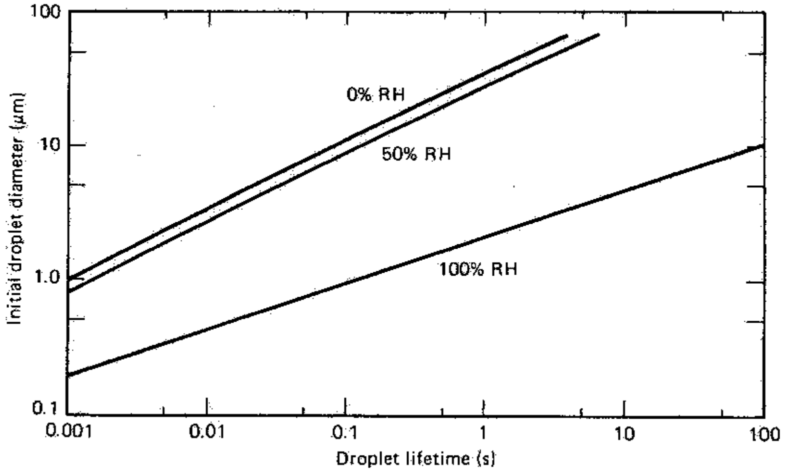

Figure 12: Impact of Relative Humidity and Droplet Size on Droplet Lifetime at 68 ^{o}F (Hinds, 199)

High-pressure mist lines are often installed beneath the roof of a building where the droplets are sprayed from the lines into the atmosphere, and the air stream absorbs the moisture. Lines installed beneath the ceiling depend on a certain percentage of particles to fall into the lower air stream, or cow area, since the air flow across the building is laminar. Laminar flow occurs when air entering at the top of the inlet remains below the roof without mixing with air near the bottom as it moves across the building. The air temperature near the floor remains high if the air is cooled in the upper air stream only and water particles are exhausted from the building before they have time to fall 10 feet. Larger particle sizes may fall to the floor prior to being absorbed into the air stream. Therefore, mixing the air stream beyond the inlet is critical for uniform cooling.

Figure 13 shows the influence of pressure on high-pressure mist nozzle capacity. For this specific nozzle, reducing the pressure from 1,500 pounds per square inch (psi) to 1.000 psi reduces the water requirements from 0.024 gpm to 0.019 gpm. This reduces water consumption by 21%, resulting in less moisture available for evaporative cooling. If adequate water supply is not available, reducing system pressure to lessen water usage has a negative impact on the cow's environment.

COOLING SYSTEM MAINTENANCE

Water quality is important to the performance of both cooling systems. Minerals in the water system result in plugged nozzles if the nozzle orifice is too small or scaling on evaporative pads. Minerals and lack of maintenance lessen the performance of evaporative cooling systems. Therefore, both systems require periodic maintenance to ensure optimum performance. Reverse osmosis, or a similar treatment process, which removes minerals from the water, is the recommended treatment method. Because adequate quantity and quality of water is essential, clear communication between the cooling system and water treatment manufacturers is extremely important. The supplier of the cooling system must also convey to the engineer(s) or designer(s) the water usage and water demands. The water system may then properly be designed

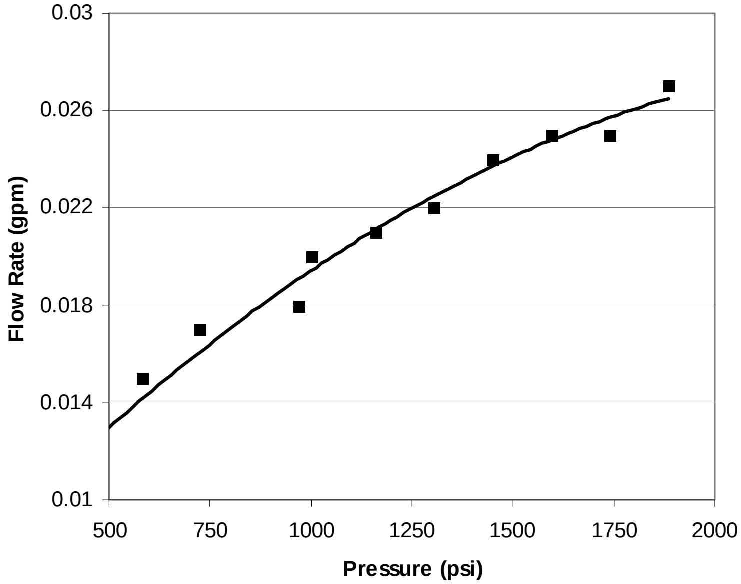

Figure 13: Impact of Pressure on Flow Rate

SUMMARY

Evaporative cooling occurs when air absorbs moisture. Evaporative pads or high pressure mist systems are two methods used to bring air in contact with moisture. In the upper Midwest, the air temperature in the cow space typically is 8 to 15 ^{o}F cooler than ambient temperatures when evaporative pads are used. The temperature differential is a function relative humidity

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Air Quality in a Low Profile Cross Ventilated Dairy Barn

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TAKE HOME MESSAGES

During the evaluation of emissions from an 800-cow low profile cross ventilated dairy freestall barn in North Dakota, gaseous emissions were found to be dominated by nitrogen-based compounds. No concentrations of hydrogen sulfide were detected inside the barn using an open-path ultraviolet spectrometer at $R^2 \geq 0.75$ of library prediction. Indoor ammonia concentrations were found to be considerably less than those reported in naturally ventilated freestall barns during previous studies. Lastly, emission rates from the 800-cow barn were lower than 100 lb/day CERCLA/EPCRA reporting limits, but they would likely increase if more than 1100 cows were housed together.

INTRODUCTION

In addition to the many details that go into the design of a low profile cross ventilated facility, air quality is an extremely important consideration. A common term used when discussing air quality is the air exchange rate. An air exchange is equivalent to replacing all of the air inside the building with fresh air. For example, during warm weather, the air exchange rate is 60 to 90 seconds. This means that every 60-90 seconds the fans move enough air to completely exchange the air inside the building with outdoor air. The air exchange rate lessens during the winter months, however. An 800-cow LPCV building in North Dakota has a wintertime exchange rate of 180 to 240 seconds. Instead of managing airflow rates based on air temperatures, this facility relies on the ability to smell ammonia to document air flow.

STUDY METHODOLOGY

An air quality study was conducted on a 420’ x 210’ 800-head LPCV barn in Milnor, ND from March 2006 through August 31, 2006. Tests were conducted 3 times using 3 randomly assigned, pre-selected ventilation (low = 20 fans, medium = 40 fans; high 78 = fans) periods lasting 2 hours each. The herd was comprised of crossbred and Holstein cows milked 3 times per day and housed in freestalls with sand bedding. A skid steer loader mounted with a rubber tractor tire was used to scrape manure to a flush-flume collection pit on the north end of the barn. Collected manure was then processed with a McLanahan sand-manure separator before it was stored in an earthen manure collection basin, along with the parlor wastewater.

Five of the 84 fans (J&D, model# 84540) were selected for representative airflow measurements. The JD fans were 48 inches in diameter with 54 inch shutter openings. Each fan was tested using the Fan Assessment Numeration System (Casey et. al, 2002). This unit was placed on the intake side and sealed to the wall. Airflow through each of the tested fans was measured at 3 different static pressures (typically 0, 0.1 and 0.2 inches of water) in order to create a fan curve for each fan.

Three temperature and humidity data loggers (HOBO H8 RH/Temp Data Logger) were placed inside the building near the evaporative pads, and three other units were placed near the exhaust fans. Two loggers were used to record ambient conditions. Data was collected every 5 minutes.

Gas emission rates were estimated using an open-path ultraviolet (UV) spectrometer system. This non-invasive method is recognized by the US-EPA for its superior precision, accuracy, and versatility. It is able to quantify dozens of emitted gases simultaneously across source areas without inhibiting the flux of various compounds that have been identified with the use of small area chambers or flux hoods. During this study a UV Sentry (Cerex Environmental, Atlanta, GA) was placed inside the barn adjacent to the exhaust fans. The UV light transmitter was placed at one end of the barn while the receiver, computer, and 3-dimensional anemometer were placed at the opposite end. The UV light beam was placed 0.5 m from the rear of the fans at a height bisecting the fans on the east side of the LPCV. Data logging software and a portable computer were used to collect data from the UV Sentry. Sample UV spectra were recorded every minute during each of the eighteen sampling periods. Sampling software was programmed to estimate the concentration from the recorded spectra: Ammonia (NH_3), Nitric Oxide (NO), nitrogen dioxide (NO_2), Nitrogen Oxides (NO_x), Hydrogen Sulfide (H_2S), other reduced Sulfide (S_2) compounds, and various Volatile Organic Compounds (VOCs).

Gas concentrations with a library spectra prediction of $R^2 > 0.75$ were used in determining average concentrations or emission rates. Measurements with predictions below the 0.75 threshold were treated as non-detected concentrations. Emission rates were calculated from the product of the gas concentration, gas molecular weight, and air velocity. Data from this study was found to meet the assumption of normality without transformation. Differences between groups were tested for significance ($P < 0.05$) using the "Differences in Least Squared Means" test of the PROCMIXED procedure. Linear regressions were calculated using PROCREG of SAS (SAS 9.1)

STUDY RESULTS

Results of the FANS assessment are presented in Table 1.

Table 1: Fan Performance from an 800-head LPCV Facility

Parameter	**Ventilation Rate**		
Testing Rate	Low	Medium	High
Number of Fans	21	40	78
Static Pressure	0.025”	0.07”	0.15”
CFM[1] per fan	20,000	19,300	14,600
CFM total	420,000	772,000	1,138,800

[1] CFM = cubic feet per minute (ft^3/min)

Gases emitted from the LPCV were dominated by nitrogen-based gases (NH_3, NO_2, NO) during the spring and summer testing periods. During the study, concentrations of H_2S were not observed at any time to have a spectra prediction greater than the $R^2 > 0.75$ threshold established by the investigators. Periodic recordable concentrations were detected for S_2, but continuous detections did not last more than 5 minutes and, therefore, were not reported. The lack of H_2S detection is not surprising. Because of the twice daily scraping of manure from the LPCV barn, a large amount of stagnant manure was not allowed to accumulate and anaerobically degrade within the barn, thus limiting H_2S production.

Ammonia concentrations and emission rates were under the lowest ventilation rate tested (420,000 cfm), as shown in Table 1 above, and measured highest during the springtime. No statistical difference was found between NH_3 concentration and emission rates at the high ventilation rate during springtime, low ventilation rate during the summer, and high ventilation rate during the summer. No statistical difference in NH_3 concentrations was observed during the medium ventilation rates of both seasons. Average observed concentrations of NH_3 (spring = 1219 $^{+}$/-5 ppb; summer = 1117 $^{+}$/- 4 ppb) were lower than the 0.3 – 3.0 ppm and 36 – 51 ppm previously reported by Zhoa et al. (2005) and Mutula et al (2004), at naturally ventilated freestall barns in Ohio and Texas, respectively.

Springtime NH_3 emissions from the LPCV barn were found to be higher than those calculated during studies of naturally ventilated freestall barns in Minnesota and Texas. As shown in Table 2, during this study NH_3 emissions at the low ventilation rate were found to be 856 mg/h/500-kg live weight during the spring and 678 mg/h/500-kg live weight during the summer. This data can be compared to 224 mg/h/500-kg live weight during the winter and 481 mg/h/500-kg live weight during the summer in the Minnesota study (Schmidt et al., 2002). Comparatively, NH_3 emission rates in the current study were found to be 21.02 µg/m^2/s during the spring and 16.65 µg/m^2/s during the summer, compared to 11 µg/m^2/s during the winter and 32 µg/m^2/s during the summer in a Texas freestall barn (Mutula et al., 2004). These differences are likely due to variations in the gaseous measurement techniques and the methods used for quantifying the ventilation rate from each barn. Various barn configurations, manure management, and desired ventilation rate also cause differences in emission rates.

Table 2: Gaseous Concentration and Emissions from an 800-cow LPCV Dairy Barn

Concentration as ppb

Season	Ventilation Rate	NH_3		NO_2		NO	
		Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Spring	Low	1,370	10.3	445^{a}	35.9	8^{ab}	5.2
	Medium	1,181^{b}	8.2	296	28.6	27	4.1
	High	1,108^{a}	8.2	417^{a}	28.6	0^{a}	4.1
Summer	Low	1,084^{a}	7.0	176^{b}	24.4	0^{a}	3.5
	Medium	1,157^{b}	7.0	145^{b}	24.5	4^{b}	3.5
	High	1,112^{a}	7.1	155^{b}	24.5	0^{a}	3.5

Emission Rate as µg/s

Season	Ventilation Rate	NH_3		NO_2		NO	
		Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Spring	Low	172,248	2,464	151,469^{b}	24,117	1,779^{ab}	2,050
	Medium	273,133^{a}	1,962	185,446^{b}	19,202	11,074	1,632
	High	377,874^{b}	1,962	385,073	19,202	0^{a}	1,632
Summer	Low	136,426	1,676	60,088^{a}	16,407	0^{a}	1,394
	Medium	268,596^{a}	1,679	91,455^{a}	16,429	1,572^{a}	1,395

	High	379,190^{b}	1,681	142,958^{b}	14,452	0^{a}	1,398

^{abc} within a column, means without a common superscript differ (P<0.05) using Differences in Least Squares Means.

Schmidt et al. (2002) determined average ammonia concentrations using continuous chemiluminescence NO analyzer and a thermal NH_3 converter (Model No. 17C Thermal Environment Instrument). Ventilation rates were calculated using the "CO_2 Balance" method described by Albright (1990). Mutula et al. (2004) also determined ammonia concentrations using a Model 17C TEI while utilizing an isolation flux chamber to determine the emission rate per square meter. In order for engineers, scientists, regulators, and air quality professionals to make accurate comparisons between study results, further research is needed.

The indoor and outdoor temperature and indoor relative humidity were significant factors in the maximum NH_3 concentration within the LPCV dairy barn during the spring, as shown in Table 3. Other factors such as outdoor relative humidity and ventilation rate were not as significant. However, during the summer, all model variables were found to be statistically significant ($P < 0.05$ level) for the prediction of maximum ammonia concentrations. Further research should be conducted to investigate the predictive relationship between maximum NH_3 concentration within the barn, with or without the use of evaporative cooling pads during the summer.

Table 3: Seasonal Regression Analysis for Ammonia Concentration at LPCV Outlet

Variable	**Estimate**	**Standard Error**	**t Value**	**Pr > t**
Spring *Root MSE = 92.55; Dependent Mean=1187.41; Coefficient Variable = 7.79; R^2 = 0.5920; Adjusted R^2 = 0.5886*				
Intercept	1174.26	165.22	7.11	< 0.0001
Temperature - Inside	117.31	16.36	7.17	< 0.0001
Relative Humidity - Inside	4.27	2.19	1.95	0.0514
Temperature - Outside	-131.88	13.67	-9.65	< 0.0001
Relative Humidity - Outside	-4.01	3.21	-1.26	0.2096
Ventilation Rate	-0.0000539	0.00003939	-1.37	0.1713
Summer *Root MSE =34.48; Dependent Mean=1117.47; Coefficient Variable = 3.09; R^2 = 0.5022; Adjusted R^2 = 0.4998*				
Intercept	-73.76	40.27	-1.83	0.0673
Temperature - Inside	53.42	2.84	18.80	< 0.0001
Relative Humidity - Inside	4.55	0.35	12.86	< 0.0001
Temperature - Outside	-16.21	2.11	-7.68	< 0.0001
Relative Humidity - Outside	0.64	0.30	2.14	0.0327
Ventilation Rate	0.000140	0.00000573	24.45	< 0.0001

Temperature = 0C; Relative Humidity = %; Ventilation Rate = ft3/min; Inside = Inside Barn; Outside = Outside Barn

Table 4 shows that the current 800-cow LPCV barn would emit a maximum of 72 pounds/day (32.8 kg/day) of NH_3 and 73 pounds/day (33.3 kg/day) of NO_2. These values are less than the 100 pound/day reporting limit required for compliance with the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the emergency notification provisions of the Emergency Planning and Community Right-to-Know Act (EPCRA). However, based on these values, an LPCV barn with more than 1090 cows should report potential maximum emission for NO_2, and an LPCV barn with more than 1107 cows should report for NH_3.

Table 4: Emission Rates from an 800-cow LPCV Dairy Barn

Emission Rate as lb/cow/day				
		NH_3	**NO_2**	**NO**
Spring	Low	0.0410	0.0361	0.0004
	Medium	0.0650	0.0442	0.0026
	High	0.0900	0.0917	0.0000
Summer	Low	0.0325	0.0143	0.0000
	Medium	0.0640	0.0218	0.0004
	High	0.0903	0.0340	0.0000
Emission Rate as lb/day				
Spring	Low	32.81	28.85	0.34
	Medium	52.03	35.32	2.11
	High	71.98	73.35	0.00
Summer	Low	25.99	11.45	0.00
	Medium	51.16	17.42	0.30
	High	72.23	27.23	0.00
Emission Rate as g/day				
Spring	Low	14,882.2	13,086.9	153.7
	Medium	23,598.7	16,022.5	956.8
	High	32,648.3	33,270.3	0.0
Summer	Low	11,787.2	5,191.6	0.0
	Medium	23,206.7	7,901.7	135.8
	High	32,762.0	12,351.6	0.0
Emission Rate as g/cow/day				
Spring	Low	18.60	16.36	0.19
	Medium	29.50	20.03	1.20
	High	40.81	41.59	0.00
Summer	Low	14.73	6.49	0.00
	Medium	29.01	9.88	0.17
	High	40.95	15.44	0.00
Emission Rate as µg/m^2/s[a]				
Spring	Low	21.02	18.49	0.22
	Medium	33.33	22.63	1.35
	High	46.12	46.99	0.00
Summer	Low	16.65	7.33	0.00
	Medium	32.78	11.16	0.19
	High	46.28	17.45	0.00
Emission Rate as mg/h/500-kg live weight[b]				

Spring	Low	856	752	9
	Medium	1357	921	55
	High	1877	1913	0
Summer	Low	678	298	0
	Medium	1334	454	8
	High	1883	710	0

[a] based on barn interior dimensions of 64m x 128m (210ft x 420ft)

[b] based on an average weight per cow of 454 kg (1000 lb)

DUST EMISSIONS

In another study, dust measurements were taken inside a 200-foot wide LPCV that had sand bedded freestalls. Particulate emissions from the three samplers were 78.2 $\mu g/m^3$ near the east end of the barn, 74.8 $\mu g/m^3$ in the barn's center, and 94.8 $\mu g/m^3$ near the west end of the barn. These values are 10 to 100 times less than recorded dust concentrations from poultry and swine units (Jerez, et al., 2006). By comparison, the U.S. Environmental Protection Agency (USEPA, 1987) and the National Ambient Air Quality Standards (NAAQS) limit primary and secondary PM_{10} dust concentration for a 24-hour sampling period to 150 $\mu g/m^3$. The purpose of the primary standard is public health protection, and the purpose of the secondary standard is to shield the public from known or anticipated adverse effects. The values obtained from this site are below the current standard. Further research is needed to investigate if dust emissions are higher when organic bedding, such as dried manure solids or sawdust, are used.

SUMMARY

Low-profile cross-ventilated (LPCV) freestall buildings are another option for dairy cattle housing. These facilities allow producers to have greater control over the cow's environment during all seasons of the year. These buildings are placed closer to the parlor, reducing time cows are away from feed and water, resulting in a smaller overall site footprint compared to naturally ventilated freestall facilities. This study evaluated the gaseous emissions from an 800-head LPCV dairy barn located near Milnor, ND across three ventilation rates during the spring (May 8 - 12, 2006) and summer (August 28 - 31, 2006). Gaseous emissions were found to be dominated by nitrogen-based compounds. Hydrogen sulfide was not detected inside the barn using an open-path ultraviolet spectrometer at $R^2 \geq 0.75$ of library prediction. Indoor ammonia concentrations were found to be considerably less than those reported in naturally ventilated freestall barns during previous studies. Lastly, emission rates from the 800-cow barn were lower than 100 lb/day CERCLA/EPCRA reporting limits, but would likely be exceeded if more than 1100 cows were housed together.

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"To see, or not to see, that is the question."
Lighting Low Profile Cross Ventilated Dairy Houses

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TAKE HOME MESSAGES

- Low profile cross ventilated freestall buildings allow implementation of long day lighting for lactating cows and short day lighting for dry cows.
- Lighting design in low profile cross ventilated buildings should provide 25 or more footcandles of light.
- Fluorescent or metal halide lights are used in lighting LPCV buildings
- The mounting height of fixtures is lower in LPCV buildings than natural ventilated freestall buildings.

INTRODUCTION

Light is a vital component in the daily operations of a dairy facility, even though lactating and dry dairy cattle require different amounts of light exposure. Increased cow performance, greater well-being and safer working conditions make lighting an important environmental characteristic. Because cows are able to move more easily through uniformly lit entrances and exits, increased quality lighting improves cow movement and efficiency. Herdsmen, veterinarians, and other animal care workers often report that easier and more accurate cow observation and care take place in well-lit facilities.

LIGHT REQUIREMENTS AND AVAILABILITY

The recommendation for lactating dairy cows is 16 to 18 hours of continuous light (16L to 18L) each day, followed by 6 to 8 hours of darkness (6D to 8D). Studies reveal that 24 consecutive hours of light do not greatly increase milk yield response, as compared to the milk yield of lactating cows exposed to only the recommended daily amount of light (Dahl et al., 1998). However, providing a 6 to 8 hour period of continuous darkness is often difficult in operations that milk three times a day. In those cases, light amount and quality are crucial. Dry cows have a short-day lighting requirement of 8 hours of light and 16 hours of dark (8L). 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). Meeting the lighting requirement of both dry and lactating cows in a LPCV facility can be challenging.

Figure 1 illustrates the daylight hours for Kansas City, KS in the course of a year. Daylight hours are defined as the hours between sunrise and sunset on the 15th of each month. As the figure shows, the maximum daylight hours are 14.9 in June, and the least amount of daylight is 9.6 hours in December. On the average, only 12.2 hours occur daily between sunrise and sunset during the year, which means an additional 25% of daylight hours are necessary when implementing long-day lighting. Even naturally-ventilated freestalls fall short of the recommended 16 to 18 hours of light because of the changing seasons.

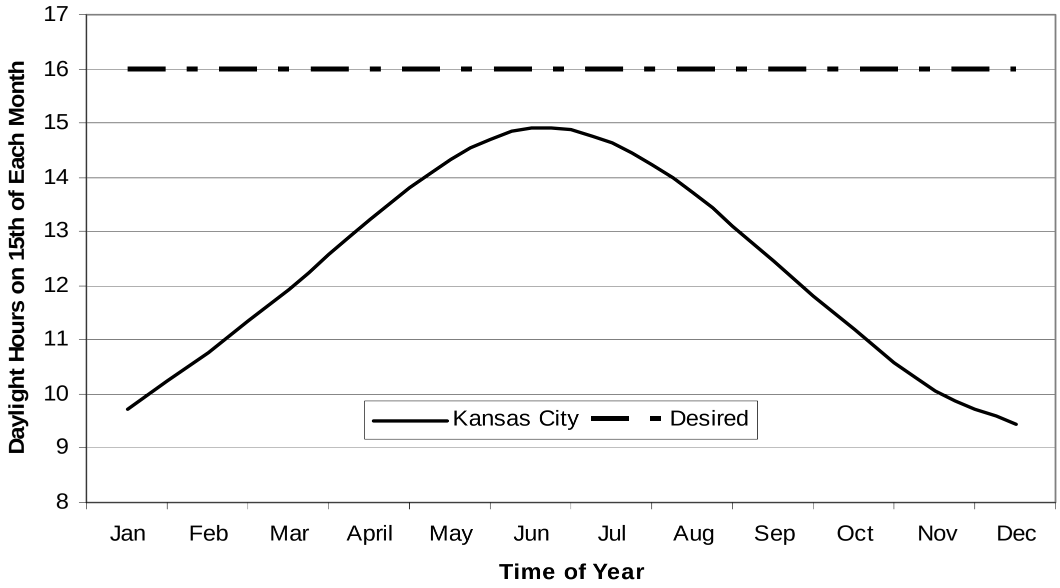

Figure 1: Daylight Hours on the 15th of Each Month in Kansas City, Kansas

ILLUMINATION LEVELS

Light intensity is expressed in footcandles (fc), or lumens per square foot. Lumens are the amount of light output from a light source, such as a lamp or bulb. Table 1 lists recommended illumination levels for different areas in a dairy facility, along with examples of outdoor light levels and recommendations for other locations. The current recommendation is to provide 15 to 20 fc during daylight hours and 1 to 5 fc during the dark period to allow for animal movement to the parlor. Though darkness is not officially defined, levels around 2 to 3 fc are considered sufficient. For low profile cross ventilated (LPCV) buildings, the daylight hour lighting should be increased to 25 to 30 fc. If 25 fc is used as the design parameter, then the current recommendation is to use the average lumens per fixture. The initial lumens per fixture may be used if 30 fc is the design parameter.

LIGHTING SYSTEM PERFORMANCE

Important performance characteristics for lighting systems in dairy facilities are: light intensity or illumination level, photoperiod or duration, color characteristics, and uniformity. The lighting equipment installed should be selected to meet the performance recommendations described.

Table 1: Recommended Illumination Levels for Outdoor Areas and Other Locations (ASABE 2006)

Work Area or Task	**Illumination Level (foot-candles)**
Various Locations on a Dairy	
Freestall feeding area	20
Housing and resting area	20
Parlor holding pen	10
Parlor pit and near udder	50
Parlor stalls and return lanes	20
Milk room - general lighting	20
Milk room – washing area	75-100
Milking parlor – loading platform	20
Utility or equipment room	20
Storage room	10
Office	50
Treatment & maternity area - General lighting	20
Treatment and maternity area - Surgery	100
Outdoor Lighting & Other Examples	
Full Daylight	1,000
Overcast Day	100
Twilight	1
Full Moon	0.1
Supermarket, mechanical workshop	70
Show Rooms, Offices, Study Libraries	50
Warehouses, Homes, Theaters	15

Illumination uniformity in dairy facilities is especially critical for visually difficult tasks or intense work areas, but general requirements are not well-established. Lighting uniformity is typically defined as the ratio of the maximum illumination level (fc) to the minimum fc value (ASABE, 2006). The American Society of Agricultural and Biological Engineers Standard EP344.3 (ASABE, 2006) recommends using the coefficient of variation (CV) to define uniformity. Chastian (1994) found a high degree of uniformity of the CV was 25% or less. The CV is an unbiased measure of uniformity. Table 2 shows the recommendations for uniformity in Standard EP344.3 (ASABE, 2006).

Table 2: Summary of Lighting Uniformity Criteria for Livestock Facilities (Chastain et al. 1997, ASABE 2006)

Task Classification	**Maximum CV (%)**	**Corresponding Spacing to Mounting Height Ratio**
Visually intensive (i.e. milking)	25	0.87
Handling of livestock and equipment	45	1.57
General low-intensity lighting	55	1.92

The initial design in low profile cross ventilated buildings should strive for an illumination uniformity ratio at 1.5 :1 to 2:1 throughout all the buildings to avoid shadows and dark spots, or a CV of 25 to 45 percent.

Fluorescent lights contain ballasts that initiate and maintain the bulbs' light. Electronic ballasts are recommended over other ballasts because they are more energy efficient, generate less heat, have a longer life expectancy, and operate and start at colder temperatures (0° F). High light output (HLO) fluorescent fixtures are available with electronic ballasts, and they generally emit 33% more light with only an 8% increase in energy usage. Magnetic and electromagnetic ballasts are not recommended because they generate waste heat, hum or click, and cause the light to flicker at cold temperatures. These ballasts also have difficulty starting at temperatures of 50°F or less.

New dairy facilities often use fluorescent and metal halide fixtures to provide lighting. Compact fluorescent lights also can be used to replace incandescent lights when the existing fixture meets the National Electric Code safety requirements for livestock buildings, but tube fluorescent lights provide the best life-cycle cost option for new construction (Chastain and Hiatt, 1998). Studies also show that T-8 lamps are more energy efficient than T-12 lamps. Table 3 lists the size, efficiency, and lamp life of common light sources used in dairy facilities.

Table 3: Characteristics of Common Lamps (ASABE, 2006)

Lamp Type	**Lamp Size (watts)**	**Efficiency (lumens/watt)**	**Typical Lamp Life (hours)**
Incandescent	60-200	15-20	750-1,000
Halogen	50-150	18-25	2,000-3,000
Fluorescent	32-100	75-98	15-20,000
Compact Fluorescent	5-50	50-80	10,000
Metal Halide	75-400	80-92	15,000-20,000
High Pressure Sodium	100- 400	90-110	15,000- 24,000

Extra light fixtures and protected compact fluorescent lights should be installed at waterers and left on for 24 hours per day in order to encourage drinking during both light and dark periods. Some factors considered in lighting system designs include building surface reflectivity, light loss due to dust and dirt accumulation, and decreased light output with increased usage. Dahl et al (1998) recommend decreasing the lumens per blub by one-third to compensate light decay in the design phase. Prompt light replacement and periodic cleaning minimizes light loss over time. Additional lighting design information for dairy facilities is available from lighting anufacturers. Software is available for designing uniform lighting through the housing area based on desired illumination.

COLOR CHARACTERISTICS OF BULBS

Sunlight is made of various wavelengths of light which produce different colors, or rainbows. The color characteristic temperature (CCT) and color rendition index (CRI) are used to describe color characteristics of artificial lights. The CCT describes the color of the light using a Kelvin temperature scale that ranges from 1,500 to 6,500 degrees K. Artificial lights with CCT values close to 6,500 K produce a white light that closely resembles natural sunshine. The CRI indicates a light's ability to render the true color of an object. CRI values range from 0 to 100. Lights with high CRI values produce light that renders true color, while lights with lower CRI values produce some color distortion of an object. Table 4 outlines CCT and CRI values for some common lights.

Table 4: Color Characteristic Temperature and Color Rendition Index Values for Common Lights (Janni 2000)

Lamp Type	**Color Characteristic Temperature (deg K)**	**Color Rendition Index**
Incandescent	2,500-3,000	100
Halogen	3,000-3,500	100
Fluorescent	3,500-5,000	70-95
High Intensity Discharge		
Mercury Vapor	n/a	20-60
Metal Halide	3,700-5,000	60-80
High Pressure Sodium	2,000- 2,700	n/a

The color characteristic temperature of fluorescent lights depends on the type of bulb installed. The last two digits in the bulb number indicate the CCT of a fluorescent bulb. For example, a fluorescent bulb with the number F32 T8 SP41 means that it is a 32-watt fluorescent T-8 (1-inch diameter) bulb with a CCT of 4,100 K.

Metal halide, high-pressure sodium, and mercury vapor lights comprise a group of long-lasting, high-intensity discharge lights that are used to light large areas because they emit large amounts of lumens, as shown in Table 4 above. Metal halide lights give off a fairly white light with a CCT value up to 5,000 K and CRI values up to 80%. As a result, their use in dairy facilities is growing. High-pressure sodium lights emit a gold or yellowish light with a CCT value up 2,700 K and CRI values up to 60% and are typically not used in the housing area. Table 5 compares the color appearance and resulting object colors of various lamps.

Table 5: Color Appearance and Resulting Object Colors for Common Lamps (Hoke. 1998)

Type of Lamp	**Color Appearance**	**Object Colors Enhanced**	**Object Colors Dulled**
Incandescent Halogen	Yellowish White	Warm Colors	Cool Colors
Fluorescent			
Warm White	Yellowish White	Orange, blue, yellow	Red, blue
Cool White	White	Orange, blue, yellow	Red
Cool White Deluxe	White	All nearly equal	None appreciable
High Intensity Discharge			
Clear Mercury	Blue/green	Yellow, green, purple	Red, orange
Metal Halide	White	Orange, yellow, blue	Deep Red
High Pressure Sodium	Yellow/orange	Yellow	All except yellow

MOUNTING HEIGHT AND SEPARATION DISTANCES

The relationship between the illumination level and lumen output from a single light or bank of lights depends on many factors, but distance between the light and the illuminated area is an important consideration.

Illumination levels decrease rapidly when the distance from the light source increases. Both the mounting height and the separation distance between evenly distributed lights effect the average illumination level (i.e., fc) (Janni, 2000). The mounting height is the distance from the bottom of the fixture to the work surface. Excessively high mounting heights waste light by dispersing it over too large of an area, and excessive separation distances decrease illumination uniformity. Standard 32-watt T-8 fluorescent lights are generally used when they can be placed seven to eight feet above the work surface. The work surface in dairy housing is usually 1-3 feet above the floor or at a height equal to the cow’s eye level while resting in the free stalls. High-light-output (HLO) 32-watt T-8 fluorescent lights are used if the lights must be placed higher, up to 14 feet above the lighted area. Table 6 provides typical mounting heights and horizontal separation distances needed to produce a standard illumination level of 20 fc.

Because cow flow is often slowed by cows stopping to investigate shadows and dark areas around corners and doorways, lights should be mounted in order to minimize shadows. In freestall barns with trusses, mount lights at or below the bottom chord so that the trusses do not block light from reaching the feed bunk and freestall areas. In milking parlors and stall barns, mount fluorescent lights below structural members and other equipment to minimize shadows.

Table 6: Mounting Heights and Separation Distances for Common Lights (Janni, 2000)

Lamp Type	**Mounting Height (feet)**	**Separation Distance (feet)**
Standard Fluorescent (32 W, T-8)	7-8	10-16
HLO Fluorescent (32 W, T-8)	9-12	12-20
Metal Halide – 175 W	11-14	14-24
Metal Halide - 250 W*	20- 35	24-28
Metal Halide – 400 W*	24-30	25- 40

* Typical for 96-112 ft wide freestall barns with 12 ft sidewalls and 4:12 roof slope

Figure 2 illustrates the spacing to mounting height ratio for three different 250 W metal halide light fixtures. As the ratio increases, more lumens are distributed outward from the fixture. Lumen distribution is determined by the diffuser, or lens covering, rather than the bulb wattage

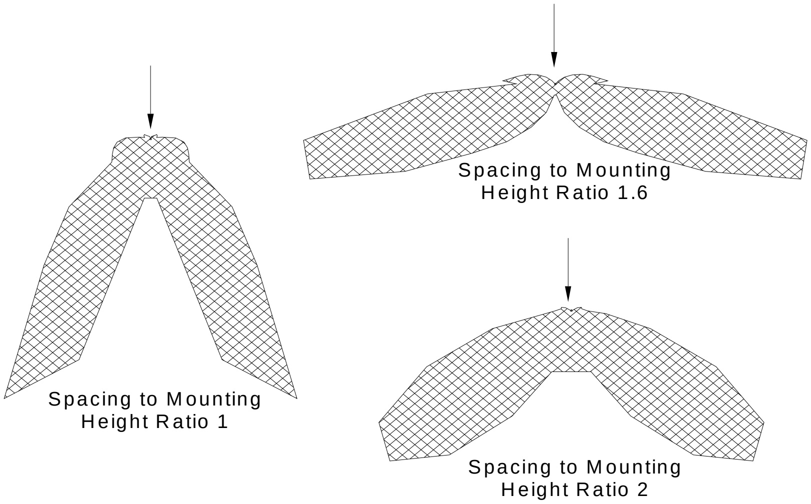

Figure 2: Impact of Diffuse on Light Pattern and Spacing to Mounting Height Ratio

The mounting height is different than the ceiling height and depends on the slope of the roof, as illustrated in Figure 3. The mounting height is higher in a building with a 4/12 roof slope as compared to a building with a 1/12 roof slope. Therefore, fluorescent or low bay metal halide fixtures are used in LPCV buildings, rather than hay bay metal halide fixtures.

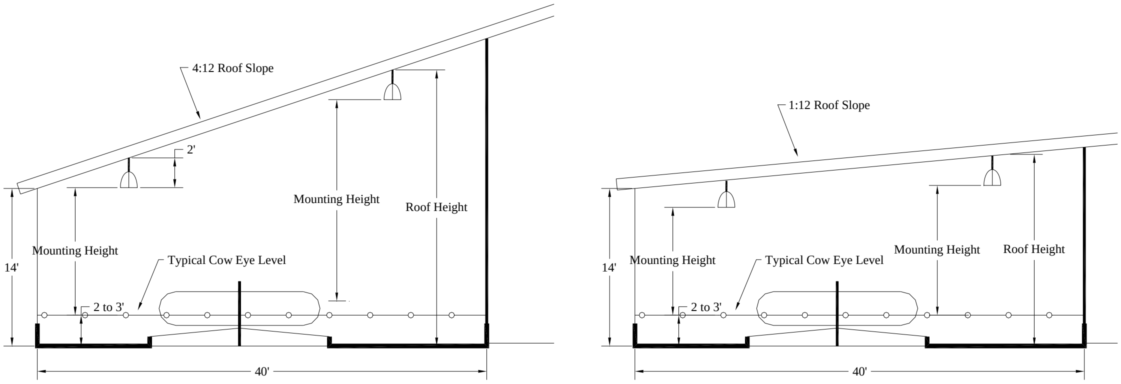

Figure 3: Impact of Roof Slope on Mounting Height in Dairy Housing

FIXTURES

Most metal halide lights used in dairy housing are either high or low bay fixtures, as shown in Figure 4. High bay fixtures require a higher mounting height and direct the light downward beneath the lamp. The diffuser, or lens, on low bay lights spreads the light pattern over a larger area. In low profile cross ventilated dairy facilities, low bay lights should be considered. The type of diffuser on the fixture determines the spacing to mounting ratio.

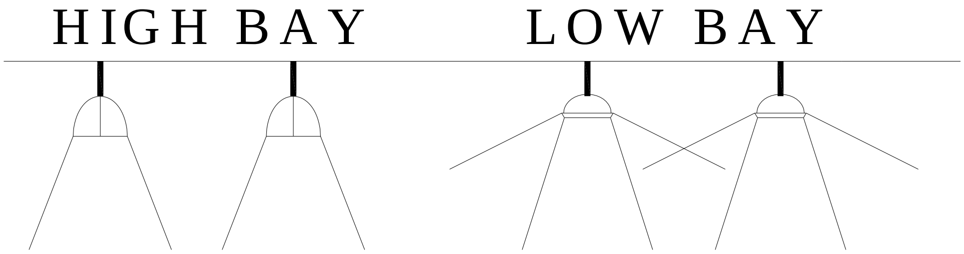

Figure 4: Comparison of High and Low Bay Lights

LUMENS AND LAMP LIFE

Manufacturers provide the angle off-center of the points at which the intensity of the light drops to 10 and 50% of the maximum value. The maximum spacing to mounting height ratio is based on the luminance midpoint between two fixtures and is equal to the luminance directly beneath a fixture. Manufacturers also provide information on initial and average lumens per bulb.

Typical lamp life information of high-intensity discharge lamps is shown in Table 7. These values are based on 10 hours of operation per day, and the initial lumens are based on the lumen output after 100 hours of use. If the lamp life is 24,000 hours or greater, then 67% of the lamps are still operational at 24,000 hours. If the rated lamp life is less than 24,000 hours, then 50% of the lamps are operating at the rate life. Operating a lamp only 5 hours per start rather than 10 reduces the lamp life to 75% of the rating. The light output decreases over time, and the average lumens is measured at 40% of the lamp life.

Table 7: Comparison of Initial and Average Lumens for Different Lamps

Type of Lamp	Initial Lumens	Average Lumens
150 W – Metal Halide	12,000	8,500
250 W – Metal Halide	22,000	17,000
400 W – Metal Halide	42,000	32,000
250 W – High Pressure Sodium	28,000	27,000
400 W – High Pressure Sodium	50,000	45,000

LPCV Light Measurements

Figure 5 shows a graph of light measurements inside an LPCV building using fluorescent lights. Light measurements, taken at points designated represent the average of the 10 readings along the pen length. Light data recorded measured the illumination in footcandles. The illumination for the building was 27 +/- 13.5 fc. Average values per location ranged from 9.9 to 44.8 fc. The average light levels exceed the normal recommendation of 15 to 20 fc for the housing area. With exception of the stalls next to the pads and fans, light levels are within or exceed the recommended light levels. Light measurements were taken when the facility was only 6 months old, so the light level may decline as the bulb efficiency decreases and dust accumulates. The uniformity of luminance was 12.7 using the data set of measured light levels and the coefficient of variation was 50 percent.

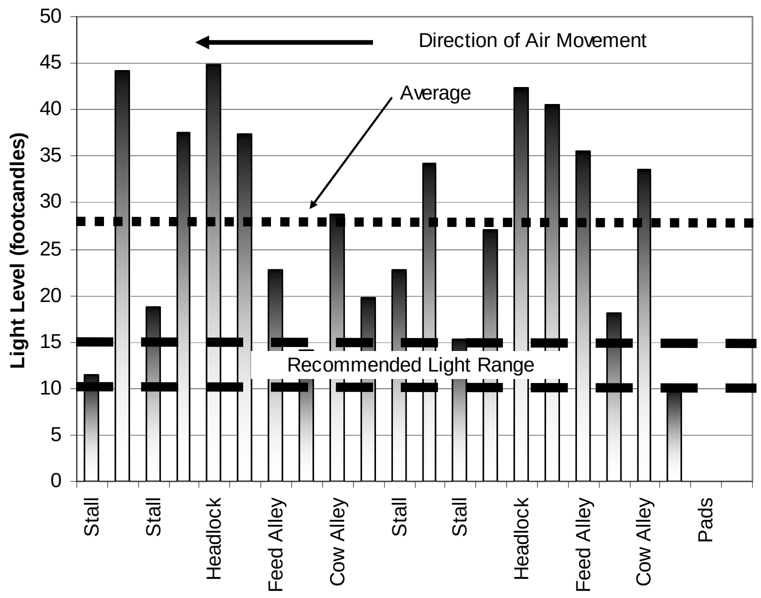

Figure 5: Fluorescent Light Levels Inside a Low Profile Cross Ventilated Freestall Facility

SAFETY AND ELECTRICAL CODES

Lights installed in dairy barns must meet National Electric Code (NEC) requirements (NFPA 70, 1996) for use in agricultural buildings and all applicable state electrical codes. UL-approved fixtures should be used instead of UL-listed fixtures and, since dairy barns are damp and dusty, lights should be watertight and constructed of corrosion-resistant materials (Article 547).Wiring in dairy facilities should also meet NEC requirements for agricultural buildings (Article 547). To minimize the potential for fire and stray voltage, a knowledgeable and qualified electrician should do all wiring.

CONCLUSION

In summary, proper lighting of LPCV facilities is essential. A lighting schedule needs to be determined from the start of operation so that each of the dairy housing areas is lit with a minimum of 25 fc. Ideally, all lactating cows need to be on a lighting schedule which provides them with 16L per day. The only time lactating cows do not experience a dark period is when they are in the milking parlor. Providing short-day lighting for dry cows can be difficult if the dry cows are housed in the same facility as the lactating cows. LPCV facilities provide a unique opportunity to control lighting, but a properly planned lighting system is essential.

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Insulation in Low Profile Cross Ventilated Freestall Facilities

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TAKE HOME MESSAGES

- A minimum R-6 insulation should be installed beneath the roof and inside sidewalls and end walls of low profile cross ventilated freestall buildings.
- All seams and holes must be property sealed to prevent moisture from condensing between the insulation and roof.
- Based on author’s observations, it appears the close-cell spray-in-place or foam-in-place insulation is preferred over the flexible batt or rigid board insulation.

INTRODUCTION

Differences in temperature cause heat to transfer from warm areas to cooler areas within a building. In order to effectively control interior temperature and limit heat transfer in low profile cross ventilated freestall dairy facilities, insulation must be installed along the roof and exterior walls. Any material that reduces heat transfer from one area to another is considered insulation. Its main functions are to conserve heat, maintain and stabilize warm interior temperatures, prevent heat loss from in or out of the building, and reduce condensation.

HEAT TRANSFER

Heat transfer is caused by conduction, convection, or radiation. Conduction occurs when two objects of different temperatures come into contact with each other. Two types of convective heat loss result when air moves over a surface. Natural convection occurs when rising hot air displaces cold air, pushing it down. Mechanical, or force convection, happens when air is moved passed an animal.

Naturally ventilated freestall buildings, which are not typically insulated, have 4/12 roof slopes that allow warm air to rise and escape the ridge opening, resulting in convective heat loss. On the other hand, the heat in an LPCV building has to be ventilated through the fans. The air exchange rate in these buildings should be high enough during the summer that no noticeable temperature rise occurs inside the building, even though radiant heat may still be transferred into the cow housing area. Radiant heat loss occurs when heat transfers from one object to another by electromagnetic waves separated in space.

The sun is an example of radiant heat transfer because it radiates traveling heat waves that are either absorbed or reflected by a surface. Increased solar radiation raises the temperature of the roof surface which, as a result, increases the temperature inside a building. A typical LPCV building allows for approximately 100 square feet of space per cow, meaning that over 200,000 British Thermal Units (BTU) of energy per cow per day may strike the roof surface during the summer months. Therefore, insulation is necessary to minimize temperature increase in the building from the sun's conductive and radiant heat. Table 1 shows the average solar radiation on horizontal surfaces at different locations in North America.

Table 1: Average Total of Solar Radiation (BTU/square foot) Per Day at Various Locations (MWPS-23)

Time of Year	**Location**			
	Albuquerque, NM 35.03 N Latitude	Davis, CA 38.33 N Latitude	Lincoln, NE 40.51 N Latitude	Boise, ID 43.34 N Latitude
January	1134	581	699	522
February	1436	942	939	858
March	1885	1480	1277	1248
April	2319	1944	1561	1789
May	2533	2342	1826	2161
June	2721	2585	2006	2353
July	2540	2540	1977	2463
August	2342	2249	1870	2095
September	2084	1833	1517	1679
October	1646	1281	1196	1156
November	1244	795	762	666
December	1034	544	633	452

CONDENSATION

Condensation occurs when warm, moist air comes in contact with the exterior shell of a metal building, such as the post, purlins, roof, or exterior walls. Condensation problems normally occur when outside temperatures are 35°F or less, and there is a combination of humid air and cool surface temperatures below the dew point. Insulation helps prevent condensation during the winter months when warm, moist air remains longer inside the building due to lower ventilation.

Relative humidity is defined as the ratio of water vapor in the air to the maximum amount of water the air can hold. A humidity level of 50% means the air is carrying only one-half of the total moisture that it could contain at that particular temperature. Because relative humidity is a function of the temperature, cold air holds less moisture than warm air even though the humidity level may be the same. Inside an LPCV, the humidity is typically 70% or greater throughout the entire year. Since the air is warmer and at a higher relative humidity inside the building, there is a greater potential for condensation problems when compared to most naturally ventilated freestalls.

In LPCV buildings, visible condensation occurs on exposed surfaces below dew point temperatures. Visible condensation control requires proper insulation or reduction of cold surface areas where condensation may take place. Increasing the ventilation rate also helps reduce the moisture content inside the building, but it may lead to the freezing of alleys and water pipes. Simply increasing the ventilation does not typically reduce visible condensation in LPCV buildings.

Concealed condensation occurs when moisture passes through the vapor retarder, or seam, and into interior roof and/or wall cavities, resulting in condensation on surfaces below the dew point temperature. Concealed condensation is very difficult to deal with and can be extremely damaging to any structure because the problems often are not discovered until they already require costly repairs.

If moisture is in vapor form, insulation performance is not seriously affected. However, the presence of water seriously hinders insulation performance, and condensed moisture can impair or destroy the insulation value.

INSULATION

Insulation is necessary in LPCV buildings year-round. In the summer months it reduces the increased temperature from the sun's heat, and during winter months it minimizes condensation problems. Three common types of insulation used are flexible batt-insulation, rigid board, and foam-in-place (spray-in-place). The least expensive insulation is the flexible fiberglass, or rolled insulation, that is commonly used in metal buildings.

Because of excess moisture from cow urine, respiratory activity, and tractor exhaust, all insulating joints and seams in LPCV buildings, including sidewalls, must be sealed. Unsealed or broken seams allow moisture to become trapped between the roof and insulation, causing the material to sag and the insulation to pull away from the roof. As a result, warm, moist air comes into contact with the cold metal roof and causes condensation. The problem continues until the insulation fails. However, seams are difficult to reseal once the tape pulls away from the insulation since the surface becomes dusty. Because seam and moisture problems are extremely common with the flexible fiberglass insulation, owners must have clear communication with the contractor about the importance of sealing the seams to extend the life of the building.

Close-cell and open cell insulations 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 weighs 1.5 to 2 pounds per cubic foot (pcf) and has an R-value (value of resistance to heat flow) of around 6 per 1-inch of thickness. This material expands 35 to 50 times its original volume. The open cell insulation has a final weight of 0.4 to 0.6 pcf when fully cured and expands approximately 150 times its original volume. The R-value is 3.5 per inch thickness. The open cell material allows moisture to enter the foam, while the close cell insulation resists water absorption. One disadvantage of the close cell material is the maximum thickness applied per application pass is generally limited to 0.5 to 1.5 inches, as compared to the open cell insulation which may be applied in one application pass. The close cell insulation has a flammability rating of 800 ^{o}F and the open cell between 300 and 400 ^{o}F. Additional flame retardants are available to spray over the surface.

Another possible insulation option is rigid board insulation. Typically, this insulating board has a white surface which enhances light reflectivity and is washable with a high-pressure system. Thickness ranges from ½ to 3 inches with an R-value of 6 per 1-inch of thickness. The end rigid board is supplied in 4 ft widths, but a manufacturer may cut the boards to match the lengths of the purlin spacing. The joints overlap on top of a purlin, so placement of the proper boards and spacing between purlins is essential during installation. As with the flexible insulation, sealing of the joints is critical to prevent condensation.

INSULATION RECOMMENDATIONS

Low profile cross ventilated freestall buildings are cold environments. The building temperature is not maintained at a set temperature using a supplemental heater or solely by heat from animals. In LPCV buildings, the temperature varies depending on the outside air temperature. Cold buildings (i.e. minimal warmth inside the building) require minimum insulating values of R-6 in walls and roofs (MWPS-34). Increasing the R-value to 9 or 12 in cold climates provides additional benefits. According to observations of winter data from LPCV buildings, insulation design should account for a maximum 30 degree F temperature difference between the outdoor and indoor air temperatures.

Radiant barrier insulation is not a good substitute for the conductive insulation needed in an LPCV facility, but radiant heat or reflective roof coatings will reduce the radiant heat load. More information on radiant heat barriers can be obtained from the US Department of Energy website (http://www.eere.energy.gov/).

VAPOR BARRIERS

Liquid water from condensation has a thermal conductivity approximately fifteen times greater than most commercial thermal insulations, and the thermal conductivity of ice is almost four times greater than water. This high conductivity requires vapor facings with very low moisture vapor transmission rate properties in circumstances where condensation may occur. The North American Insulation Manufacturing Association recommends that metal building insulation be faced with a vapor retarder with a maximum 0.10 US permeance. Even the best vapor retarder becomes inadequate if leaky seams are present, so all punctures, penetrations, and holes must be repaired with tape to maintain continuity of the vapor retarder.

Vapor retarder facings are available in a wide variety of styles and performance properties. Styles range from plain white vinyl film to laminated composites. Facings differ in strength, color, light reflectivity, and their ability to prevent moisture from entering the insulation.

A 6-mil polyethylene film is often used in other livestock buildings as a vapor barrier. Screw holes and joints may create many openings for moisture to pass through but, overall, significant reductions in moisture absorption occur when compared to the liner feet of seams in blanket or foam-in place insulation.

SUMMARY

The roof, sidewalls and end walls of LPCV buildings should be insulated to reduce summer heat loads, winter heat loss and condensation. The insulating material selected should have a minimum R-6 value. Condensation is a problem inside an LPCV building if the warm moist air contacts cold exterior metal surfaces. Non spray-on insulation material requires sealing of all seams or joints.

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Assessment of Traffic Patterns in LPCV Facilities
“A Collection of Organized Things”

J. P. Harner and J. F. Smith, Kansas State University

Take Home Messages

- Milking activities and manure removal are independent procedures, but they interact in low profile cross ventilated housing systems.
- Increasing the number of lactating cow groups may be necessary to reduce the manure scrape distances and time required to clean an alley.
- There are advantages in moving the flush plume from the end to the middle of the pen, irrespective of the number of lactating cow groups. Greater reduction in travel distance is achieved as pen length increases.
- Allow for a pen(s) at the end of the parlor return lane to hold 50% of the cows in a pen so adequate time is allowed for scraping alleys and bedding freestalls.

INTRODUCTION

Assessment of various dairy activities is helpful in evaluating traffic flow in a dairy after it is constructed. Generally, the assessment is based on visual observation and discussions with key personnel. However, prior to construction, a successful dairy requires planning and integrating various components into a unified system, or a collection of organized things. There are many individual systems that must be organized and coordinated for the dairy to operate successfully and traffic to flow smoothly. Success is simply accomplishing what was proposed, and a successful system recognizes that these functions not only interact, but they are interrelated and interdependent. Successful dairies are simple to assess because they operate as unified system.

PROCEDURE INTERACTION

Two independent but interrelated systems that impact traffic flow in a dairy are the milking activities and manure removal. These activities are interrelated because cows are not usually returned to a pen from the milking parlor or transfer lane until manure has been removed from the front or feed alley. Understanding how these two systems impact one another is critical in planning a low profile cross ventilated dairy.

A model was developed to evaluate the interaction between milking and manure removal from pen alleys. Inputs used in the model were as follows:

1. 3,000 lactating cows producing 150 pounds of manure per cow per day
2. 72-stall rotary parlor operating at 90% efficiency (with 7.5 seconds of stall entry time)
3. Pen length based on 1 to 1 stocking density of the feed line
4. Feed space equal to 24 inches per cow. Frequency of manure scraping in the pens equals the milking frequency
5. Rubber tire used for scraping is 8 feet in diameter

5. Maximum depth of manure limited to 7 inches (the height of the freestall curb)
6. Capacity of the rubber tire used for scraping equals the volume of half the tire's diameter plus 25% extra that flows in front of the tire
7. Forward and backward travel speed of the skid steer is 5 miles per hour (mph)
8. Skid steer pushes manure 60% of the time – remainder of the time is for backing up, moving between lanes, and closing gates
9. Additional manure in front of a tire flows at capacity around the edges of the tire
10. Use of a single operator to clean the pens.

Variable inputs in the model were the pen size, plume location and milking frequency. A ratio of milking to manure handling (M2M) greater than 1 indicates that the time for cleaning a pen is less than the time required for milking. An M2M ratio of 1 or less occurs when the time required for cleaning a pen is equal to or greater than the required milking time. In that case, either additional operators are needed or a reduction in parlor throughput is necessary to provide adequate time for manure removal.

Table 1 shows the results of the model for a 3,000 lactating cow dairy. Traditional design guidelines of 8 pens of cows are compared to an increased number of groups, such as 10 or 12. If the plume is located at one end of the alley, a single operator does not have adequate time to clean the pens when milking 2 times per day, regardless of the number of groups. Cleaning the alleys only twice a day when milking 2 times per day requires the operator to move 50% more manure when the pens are scraped. The M2M ratio equals 0.7 for 8 groups, 0.8 for 10 groups, and 1.0 for 12 groups. When milking 3 times per day, the M2M ratio equals 1.0, 1.3 and 1.5 for 8, 10 and 12 groups, respectively. A second operator or a redesign prior to construction may be necessary if the dairy is designed with 8 groups, has an end location of the plume, and the frequency of milking is based on 3 times per day. In naturally ventilated freestall facilities, adding 10 to 20 additional minutes to the milk time in order to compensate for the extra cow travel time to and from the parlor often provides adequate time to thoroughly clean the pens.

Table 1: Impact of Pen Size, Number of Groups, Milking Frequency and Plume Location on Milking to Manure Ratio

Pen Size	Number of Groups	Milking Frequency	Plume Location	Time Requirements per Pen			Ratio of Milking to Manure Handling
				Milking Time (min)	Manure Scrape Time (min)	Single Alley (min)	
375	8	2X**	End of Pen	52	74	37	0.7
375	8	3X*	End of Pen	53	52	26	1.0
300	10	2X	End of Pen	42	50	25	0.8
300	10	3X	End of Pen	42	32	16	1.3
250	12	2X	End of Pen	35	36	18	1.0
250	12	3X	End of Pen	35	24	12	1.5

375	8	2X	Middle of Pen	52	40	20	1.3
300	10	2X	Middle of Pen	42	28	14	1.5
250	12	2X	Middle of Pen	36	20	10	1.8

*Assumes a rubber tire reaches capacity after 150 ft when alleys are scraped 3 times per day
**Assumes a rubber tire reaches capacity after 100 ft when alleys are scraped 2 times per day

The lower half of Table 1 shows the impact of moving the plume to the middle of the pen for a herd milking 2 times per day. Changing the location of the plume reduces the scraping distance (and equipment travel time) to a maximum distance of half the pen length. When the plume is located at the end of a pen, at least 50% of the manure must be scraped over half of the pen length. Changing the plume location increases the M2M ratio from 0.7 to 1.3 for 8 groups, from 1.0 to 1.5 for 10 groups, and from 1 to 1.8 for 12 groups when milking 2 times per day.

Table 2 shows the impact on travel distance of a skid steer or tractor-mounted scraper blade when the plume is moved to the center of a pen. The travel distance per day per pen is decreased by 40 to 50% when the plume is relocated to the center of a pen. Not only is the milking to manure ratio impacted, but the energy use and cost of equipment on the dairy are also positively affected.

Table 2: Impact of Scraping Frequency, Location of Plume and Pen Length on Skid Steer Travel Distance (miles) Per Day When Scraping Two Alleys

Manure Scrape Frequency	Location of Plume	Pen Length (feet)			
		300	600	750	900
3X*	End of pen	1.0 miles	3.4 miles	5.1 miles	7.2 miles
3X	Middle of pen	0.7 miles	2.0 miles	3.8 miles	4.1 miles
2X**	End of pen	0.9 miles	3.2 miles	5.3 miles	6.8 miles
2X	Middle of pen	0.8 miles	1.8 miles	3.0 miles	4.4 miles

*Assumes with 3X scraping the rubber tire reaches capacity at 150 ft
**Assumes with 2X scraping the rubber tire reaches capacity at 100 ft

Milking Activity Considerations

Though milking and manure removal need to be considered together when designing an LPCV facility, specific considerations should be taken into account in regards to milking activity and its impact on traffic flow. Walking distance, defined as the distance from the gate exiting a pen to the holding pen of the parlor, plays a key role in the time needed for milking. Typically, four and six-row freestall and dry lot dairies are designed to limit one-way walking distance to 2,000 feet or less per day. This design criterion necessitates that a dairy milking 2 times, 3 times, or 4 times per day has pen exits within 1,000, 700 and 500 feet of the parlor. Often in naturally ventilated freestalls at least two or more pens of cows are located at maximum distances from the parlor. Maximum walking distances are often exceeded if exercise lots are placed between freestall buildings. In low profile cross ventilated freestalls, the distance of the farthest pen exit to the holding pen is usually less than 400 feet with daily one-way walking distances of 1,200 feet or less, regardless of milking frequency. As a result, cows return from the milking parlor to the pen more quickly and have more time to feed and rest. The ability to shorten walking distance during milking and provide more time for cows to rest and feed are positive benefits of low profile cross ventilated dairy facilities. However, rapid manure removal needs to also occur so cows are not left standing in the transfer lane waiting for feed, water or rest.

Manure Removal Considerations

Specific considerations regarding traffic flow are also necessary when contemplating the best manure removal system. Parlor type also influences manure handling procedures. Rotary parlors enable individual cows immediately to return to a pen upon completion of milking rather than exiting as a group from a parallel or herringbone parlor. If a rotary parlor is being used, the first cow milked will return approximately 3 minutes faster than when a parallel or herringbone parlor is used. During the time that cows are away for milking, distribution also occurs within a pen. Observations of a naturally ventilated dairy with a D16 parallel parlor show 40 minutes, on average, is the quickest the first cows departed and returned to 108-stall pens located within 500 feet of a parlor (Figure 1). However, the last cows were away from the pen for an average of 73 minutes. The pen average per shift for travel times and milking was 55 minutes. This provides adequate time for scraping alleys and grooming and bedding freestalls.

In LPCV buildings, some cows may be ready to return to a pen before other cows have exited the same pen if they are the first group of the milking shift. The first cows through the milking parlor may be able to return to the pen in 10 to 15 minutes. Ideally, an alley should be cleaned in 15 minutes or less in an LPCV building. Most low profile cross ventilated dairies opt to scrape rather than flush the front (feed) and back (cow) alleys in a pen. Scraping requires more time for cleaning alleys than flushing.

Another manure removal factor that must be considered is the bedding of freestalls. The front alley is generally cleaned prior to bedding the stalls. On non-bedding days, cows are allowed to return to the front alley with access to the feed line while the back alley is scraped. Access to the pen is not possible on bedding days since the bedding equipment utilizes the front alley for bedding while the back alley is being scraped. The return lane between buildings may be used on naturally ventilated freestalls as a temporary holding pen during the bedding operation. This is not possible in low profile cross ventilated freestalls, though, because the parlor is within 50 feet of the housing area. Separate travel lanes to and from the parlor may help improve cow flow in the pens closest to the parlor.

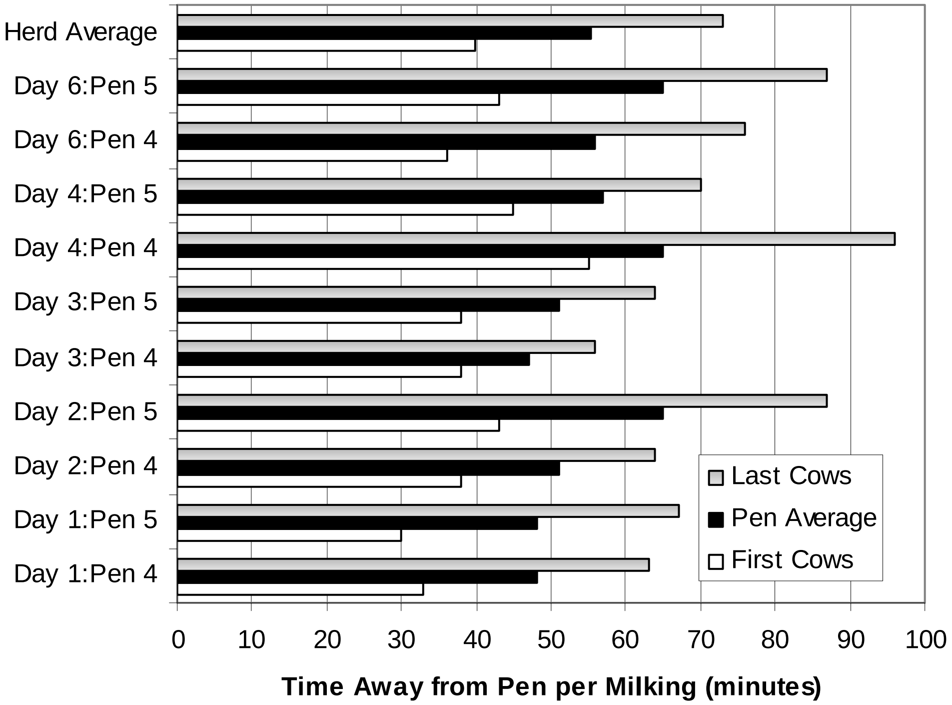

Figure 1: Time Available for Cleaning Alleys, Grooming and Bedding Stalls Based on a Time Motion Study on a Dairy with a D16 Parlor and 500 Feet Walking Distances

Exit / Return Lane Recommendations

The width of exit and return lanes should be increased to prevent having to back up the cows and interrupt milking in LPCV facilities. Current recommendation is to allow enough space in the exit and return lanes to hold 50% of the cows in a group.

Summary

Milking activities and manure removal are two independent but interrelated and crucial systems on a dairy. Understanding how the two systems interact to affect traffic flow is extremely important when designing a dairy. During the design phase, the planners should carefully compare the increased cost of moving a plume to the center of the pen versus utilizing a second operator or experiencing a reduction in parlor performance. Low profile cross ventilated freestall dairies have unique characteristics, as compared to dry lot or traditional 4 or 6-row freestall facilities. Careful planning and attention to interacting details, activities, or functions that may impact dairy traffic flow result in a successful, unified system. The design process allows producers the opportunity to look at all the options and make sound decisions for their operations. There will not be one solution for all dairies.

Economic Considerations of Low Profile Cross Ventilated Barns

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TAKE HOME MESSAGES

- Low-profile-cross-ventilated (LPCV) barns provide an opportunity to significantly reduce the temperature variability in the barn.
- Increasing the percentage of time cows are in the thermal neutral zone allows both milk production and feed efficiency to be increased.
- Increased milk production along with improved feed efficiency result in over $100/cow higher returns for LPCV barns compared to naturally ventilated freestall barns.
- Economic benefits associated with improved reproduction and herd health would likely be realized that were not explicitly accounted for in this analysis.
- Operating costs for LPCV barns are slightly higher due to higher electricity requirements and increased feed associated with higher milk.
- When investment costs are spread over their useful life, the higher profitability of LPCV barns can support higher investment per cow.

INTRODUCTION

When thinking about their cow housing options, producers incorporate a number of factors into their ultimate decision. Obviously if the dairy wants to be competitive and remain in business in the long run, one of those factors needs to be the expected economic returns associated with the different housing types. While examining projected economic returns associated with various housing types (or any other production decision) does not guarantee things will play out exactly as projected, it can help producers avoid making costly mistakes and also realize some of the potential financial risks associated with their decisions.

Depending on location, producers will typically have a number of housing options they can consider. Furthermore, within a particular housing type there are many variants to consider (e.g., natural ventilated freestalls with heat abatement configurations). The housing type and the specific configurations have trade-offs such as: labor requirements, ability to manage cow comfort, investment required, and operating costs. This paper does not attempt to cover the gamut of housing types and configurations. Rather, it looks to compare the expected costs and returns associated with two specific facility types – (1) naturally ventilated (NatVent) freestall buildings with fans and soakers in place for heat abatement and (2) a low-profile-cross-ventilated (LPCV) freestall building with evaporative pads. It was assumed that both facility types had the ability to provide long day lighting for lactating cows and short day lighting for dry cows. Investment for the naturally ventilated freestall facility is based on 4-row configuration. The investment for the cross-ventilated facility is based on a 16-row LPCV building with an additional bay on each end to reduce the number of doors and to facilitate vehicle traffic.

The projected budgets used for this analysis are patterned off the Kansas State University projected dairy budget for a 2400-lactating cow freestall dairy (Dhuyvetter et al., 2007) and are presented on both a "per cow" and "per cwt" basis. As with any projected budgets, results are conditional upon numerous assumptions that may or may not hold over time. Therefore, in addition to estimating the expected costs and returns of the two facility types, referred to as the baseline scenario, this analysis includes sensitivity analyses around some of the key assumptions (e.g., investment, production). Because the primary objective of this analysis is to examine how LPCV barns compare with naturally ventilated freestall barns from an economic standpoint, discussion will focus on *differences* in costs and returns between the two housing types. In other words, absolute levels are not as critical for this analysis as differences that might exist.

ASSUMPTIONS

Assumptions were required for many factors related to income and costs, however, key drivers in differences are primarily related to differences in investment, milk production, feed efficiency, and utilities. This analysis did not attempt to explicitly account for differences in reproduction or health.

The cost of building a dairy can vary significantly temporally and spatially and thus this is somewhat of a "moving target" from an analysis standpoint. Initially, it was assumed that both systems would require an investment of $4,650 per cow in the herd (i.e., lactating and dry cows) for buildings and equipment, including rolling equipment.[1] Land was included at a cost of $5,500 per acre and it was assumed the NatVent facility would require 50 acres compared to 40 acres for the LPCV facility.

Milk production in the baseline scenario for NatVent is assumed to be 23,000 pounds per cow per year compared to 24,000 pounds for the LPCV system. This increase in milk production is driven principally be three factors: (1) increased milk related to improved feed efficiency (increased DM digestibility) because cow is kept in the thermal-neutral zone a higher percentage of the time (see Smith et al., 2008); (2) improved reproduction, due to less heat stress, which reduces the days in milk for the herd and also results in a more consistent calving pattern; and (3) improved overall health and reduced lameness.

Figures 1 and 2 show summarize the weather data that was used and the relationship between ambient and barn temperatures used in this analysis. Figure 1 demonstrates that the advantage the LPCV barn has in avoiding very cold days as well as hot days. While the NatVent facility was assumed to have fans and sprinklers, it was assumed that it could not cool the barn down near as much as could be done with the LPCV barn. On real cold days it is assumed that barn temperature will be slightly warmer than the ambient temperature due to body heat from the cows, but as with high temperatures, the NatVent barn will be considerably colder than the LPCV barn. Figure 2 incorporates the data from Figure 1 with a distribution of annual temperatures for Sioux Falls, SD (Anon. 1978) to show the distribution of temperatures in the different barns throughout the year. The NatVent facility reduces the areas in the tails of the

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[1] This value was based on an informal survey of several contractors as to what it would cost to build both naturally ventilated and cross ventilated freestall barns.

ambient distribution, but not near as well as the LPCV facility. This much more stable environment is what leads to more milk production and the improved feed efficiency.

Total feed efficiency (pounds of milk produced per pound of feed on a dry matter basis) was estimated to be 1.30 for the NatVent facility compared to 1.34 for the LPCV facility. This difference was due to higher milk production for cows in the LPCV facility with similar feed intake levels due to improved digestibility during periods of low temperatures, and also because of decreased maintenance energy requirements during periods of high temperatures.

While utilities do not have near as large of impact on profitability as milk production or feed costs, this cost will vary between the two systems. It was assumed that the LPCV facility would require 50% more electricity (3.0 kW/cow/day compared to 2.0 kW/cow/day for the NatVent facility). The cost of utilities was based on electricity at 6¢ per kilowatt.

The following are other assumptions that impact profitability, and were the same for both housing types unless specified otherwise.

- **Cow numbers**: 2,400 lactating cows, 2,832 total cows (lactating + dry).
- **Milk price**: gross price of $18.50/cwt.
- **Milk hauling:** $0.75wt.
- **Coop fees and promotion:** $0.25/cwt.
- **Calves sold:** based on a 95% calf crop and selling all calves at birth (heifers = $450/head and steers = $50/head).
- **Cull cows sold:** assumes cull income is realized on 28% of the herd even though 34% of the herd is replaced annually. The 6% with no income represents cow death loss and cows with zero salvage value (cull cow value = $933/head).
- **Feed:** lactating cow feed = $13.56/cwt (DM) and dry cow feed = $7.57/cwt.
- **Labor:** based on 25 full-time persons (113 cows per employee) at an average of $38,000 (salary + benefits).
- **Veterinary, drugs and supplies:** costs for prevention and treatment and general dairy supplies (total =$140/cow).
- **Water:** water costs based on 140 gallons/cow/day in NatVent and 145 gallons/cow/day in LPCV (difference is due to higher milk production) at a cost of $1.55/thousand gallons.
- **Fuel, oil and auto expense:** share of the farm car and trucks plus gasoline, diesel and oil for scraping and hauling manure and for hauling feed to the dairy herd (total = $60/cow)
- **Building and equipment repairs:** annual building and equipment repairs were calculated as 2.5% of the total investment.
- **Replacements and breeding:**
  - **Capital replacement:** price of a heifer replacement ($2,000/head) times the replacement rate (34%).
  - **Semen, A.I. services, and supplies:** includes semen, artificial insemination services and supplies.
  - **Interest:** 8% interest is charged on the value of the breeding herd, which is based on the cost of replacement heifers entering the herd.
- **Professional fees (legal accounting, etc.):** business costs allocated to the dairy enterprise ($3000/month for dairy).

- **Miscellaneous:** miscellaneous costs (subscriptions, education, etc.) allocated to the dairy enterprise ($50,000/year for the dairy + $5/cow).
- **Depreciation on buildings and equipment:** depreciation is based on the total original cost less the salvage value of buildings and equipment on a per cow basis divided by the estimated life. The useful life is assumed to be 20 years for buildings and improvements and 7 years for equipment. A salvage value of 10% percent is assumed on buildings and improvements and 20 percent on equipment.
- **Interest on land, buildings and equipment:** interest is charged on the land investment at a rate of 5% and one-half the average investment [(initial cost + salvage value) ÷ 2] for buildings and improvements and equipment at a rate of 8%.
- **Insurance and taxes on land, buildings and equipment:** insurance on buildings and equipment is based on the original cost times 0.25%, taxes are based on 1.5% of the original cost for buildings and improvements and 0.50% for land.
- **Interest on operating costs:** calculated on one-half of operating costs at a rate of 8%.

CALCULATED VALUES

Given the different assumptions, costs and returns, hence profitability, could be estimated. There are several “results” that are useful to examine when considering the relative profitability of the two housing types.

- **Returns over total costs:** represents the profit earned by the dairy. It is important to note that the budgets used here include depreciation and interest on all assets and thus returns over total cost will not match up with cash flow (i.e., net cash flow is not a good measure of profitability)
- **Breakeven milk price to cover total costs:** represents the price needed for milk per cwt. to cover total costs of production. Assumes government payment, calf and cull income and all costs remain constant.
- **Asset turnover:** (returns per cow divided by total assets) asset turnover is the percentage of total investment recovered by total returns. Inverting this measure allows different enterprises to be compared on the basis of capital required to generate a dollar of gross income.
- **Net return on assets:** [(returns over total costs + interest on breeding herd + interest on operating costs + interest on land, buildings and equipment) ÷ assets] net return on assets is the percentage return on investment capital (both borrowed and equity). This measure enables comparisons to be made between enterprises as well as other investment alternatives.

RESULTS

Table 1 shows the projected budgets for the two housing types based on current price and cost estimates. The first obvious result is that neither system is profitable given the assumptions. This suggests that even though milk prices are considerably above historical averages, they are not high enough to offset the high costs of production dairy producers are currently facing. It is important to keep in mind that the returns over total costs in these budgets reflect full economic costs and thus somebody with 30-50% equity in their dairy could still experience positive cash flows even though profits are negative.

While the negative profits are relevant, they are not the focus of this particular study. Rather, the *relative* profitability of the two housing types is the focal point. The low-profile-cross-ventilated (LPCV) ban has $115/cow advantage over the naturally ventilated (NatVent) freestall barn. This advantage is driven by two factors – milk and feed. The 1,000 additional pounds of milk generated an extra $185 of income per cow and this only required about $37 of feed to accomplish. The reason feed did not increase as much as might be expected is because of the better temperature control in the LPCV barn where cows are kept in the thermal neutral zone a higher percentage of the time (see Figure 2). In addition to having higher feed costs, the LPCV barn also had about $22/cow higher utilities costs because of the high electricity usage and $10/cow more in hauling and promotion cows due to the added milk. The LPCV barn had about $1/cow lower costs associated with land because of a slightly smaller facility footprint, however, on costs of over $5,000/cow/year this is quite insignificant.

Tables 2 and 4 show how return on assets (ROA) (Line G of the budget) vary as milk production and total facility investment vary for NatVent and LPCV, respectively. These tables allow dairy managers to examine at what point the two systems might be comparable. For example, the baseline ROA for the LPCV barn is 3.10% compared to 1.36% for the NatVent barn. Looking at Table 2 it can be seen that even if the naturally ventilated barn were to cost $750/cow less, returns would still be lower unless they could get production within 500 pounds of what is in the LPCV barn (i.e., ROA = 3.19% at milk production of 23,500 pounds and facility investment of $4,737). Similarly, looking at Table 4 it can be seen that even if milk production is not higher with the LPCV barn (i.e., it was at 23,000), the returns are still better than the NatVent barn because of the improved feed efficiency. Figure 3 shows ROA at various production levels for three different investment levels (baseline +/- $500 per cow). When viewed this way it can readily be seen the milk production and investment combinations that result in a similar ROA.

Tables 3 and 5 show returns over total costs ($/cow/year) at various production and facility investment levels for NatVent and LPCV barns, respectively. Figure 4 shows the relationship between milk production and returns over total costs ($/cow/year) for the two different housing types.

Another potential benefit of better cow comfort associated with heat abatement is reduced culling rates. In the projected budgets, each 1% reduction in culling rate increases returns/cow/year about $12. Given the increases in energy costs recently, one concern about the LPCV barn is the increased requirements for electricity. Given the levels used in these budgets, an increase of 2.5¢ per kilowatt reduces the advantage for the LPCV barn by approximately $10/cow. Thus, while the increased electricity requirements cannot be overlooked, other factors impact profitability much more.

SUMMARY

Low-profile-cross-ventilated (LPCV) freestall barns appear to offer a viable alternative to the traditional naturally ventilated (NatVent) freestall barn. Based on the projections used in this analysis, the LPCV barn resulted in almost a 2% higher return on assets and about $115/cow advantage in returns over costs. Being able to better control temperature and manage cow comfort should result in increased milk production and improved feed efficiency which lead to increased profitability. Other benefits associated with increased cow comfort (e.g., reduced culling, improved reproduction) were not explicitly accounted for and thus the advantages for LPCV barns reported here are likely conservative. Total costs per cow are slightly higher with LPCV barns due to increased electricity usage and slightly higher feed costs due to increased milk production. Given a 1,000 pound higher production level, even if LPCV barns require a larger initial investment per cow ($500 or more) they are still more profitable than the naturally ventilated barn when costs are spread over the useful life of the investment.

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Figure 1.

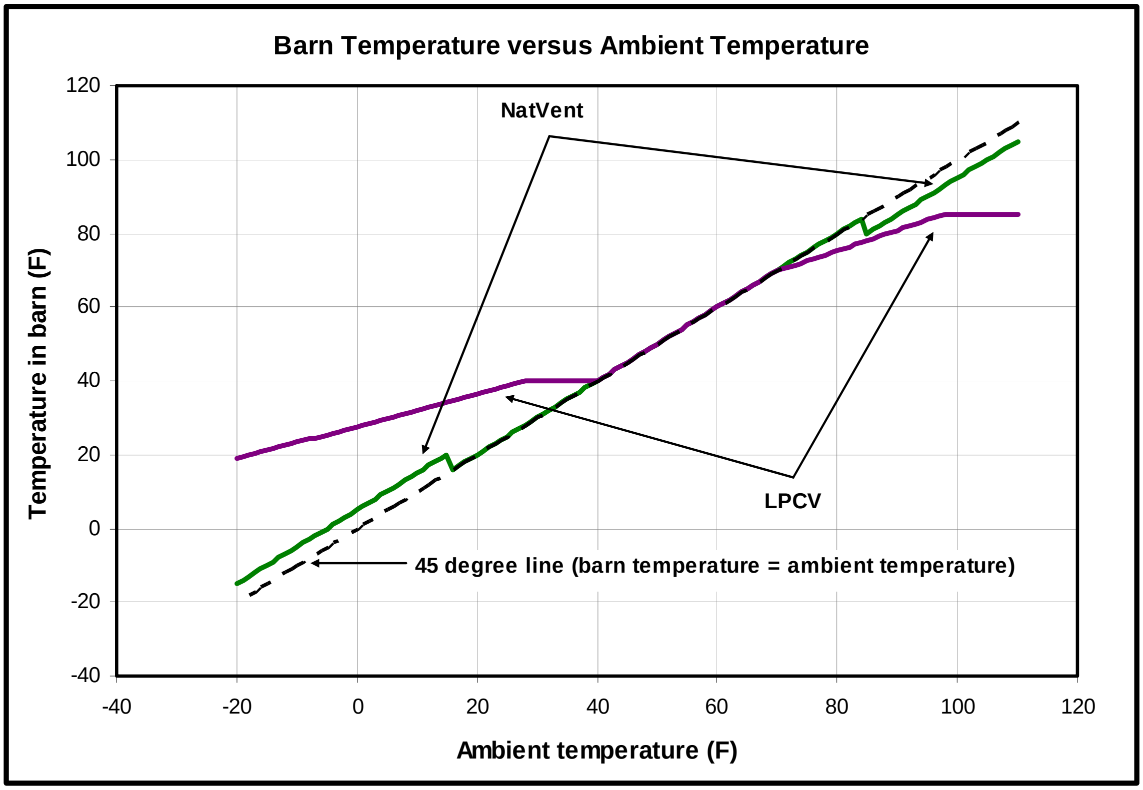


Figure 2.

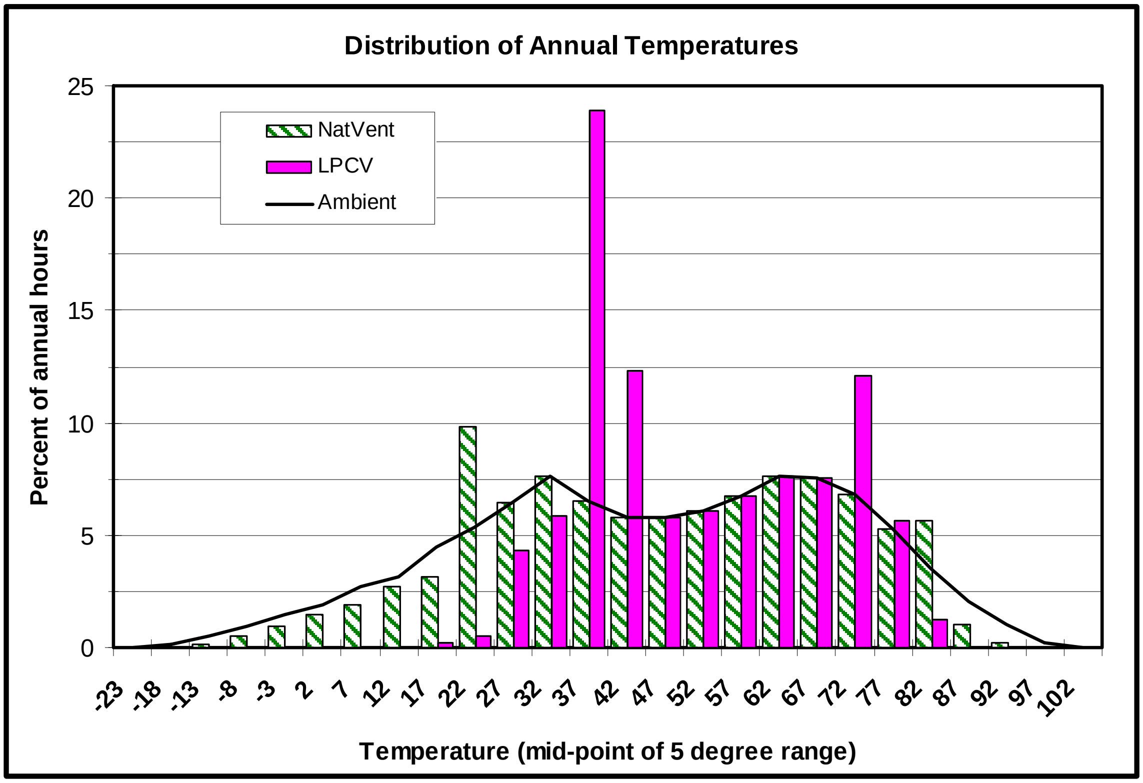


Table 1. Cost-Return Projection --- 2,400 Lactating Cow Freestall Dairy[1]

	Natural ventilation[2]		Cross ventilation		Difference[3]
	per cow	per cwt	per cow	per cwt	per cow
PRODUCTION LEVEL, lbs milk sold	23,000	230	24,000	240	1,000
RETURNS PER COW					
1. Milk sales @ $18.50/cwt.	$4,255.00	$18.50	$4,439.96	$18.50	$184.96
2. Volume premium	0.00	0.00	0.00	0.00	0.00
3. Government payment (MILC)	0.00	0.00	0.00	0.00	0.00
4. Calves sold: 95% x $246/head	233.70	1.02	233.70	0.97	0.00
5. Cull cows sold: $933,/head x 28.0%	261.20	1.14	261.20	1.09	0.00
A. GROSS RETURNS	$4,749.90	$20.65	$4,934.86	$20.56	$184.96
COSTS PER COW:					
6. Feed	$2,555.34	$11.11	$2,592.13	$10.80	$36.80
7. Labor	335.45	1.46	335.45	1.40	0.00
8. Supplies, drugs, and veterinary	140.00	0.61	140.00	0.58	0.00
9. Somatotropin (rbST)	0.00	0.00	0.00	0.00	0.00
10. Utilities and water	125.47	0.55	147.37	0.61	21.90
11. Fuel, oil, and auto expense	60.00	0.26	60.00	0.25	0.00
12. Milk hauling and promotion costs	230.00	1.00	240.00	1.00	10.00
13. Building and equipment repairs	116.25	0.51	116.25	0.48	0.00
14. Breeding/genetic charge:					
a. Capital replacement: 34% x $2000/head	680.00	2.96	680.00	2.83	0.00
b. Semen, A.I. services, and supplies	52.50	0.23	52.50	0.22	0.00
c. Interest	160.00	0.70	160.00	0.67	0.00
d. Insurance	20.00	0.09	20.00	0.08	0.00
15. Professional fees (legal, accounting, etc.)	12.71	0.06	12.71	0.05	0.00
16. Miscellaneous	22.66	0.10	22.66	0.09	0.00
17. Depreciation on buildings and equipment	230.03	1.00	230.03	0.96	0.00
18. Interest on land, buildings, and equipment	210.65	0.92	209.68	0.87	-0.97
19. Ins. and taxes on land, bldgs and equip.	77.46	0.34	77.34	0.32	-0.12
B. SUB TOTAL	$5,028.51	$21.86	$5,096.12	$21.23	$67.61
20. Interest on 1/2 operating costs @ 8.0%	140.71	0.61	143.06	0.60	2.34
C. TOTAL COSTS PER COW	$5,169.22	$22.47	$5,239.17	$21.83	$69.95
D. RETURNS OVER TOTAL COSTS (A - C)	-$419.32	-$1.82	-$304.31	-$1.27	$115.01
E. BREAKEVEN MILK PRICE, $/cwt:		$20.32		$19.77	$0.56
21. Lactating cow feed cost, $/head/day	$7.60		$7.71		$0.12
22. Dry cow feed cost, $/head/day	$2.27		$2.27		$0.00
F. ASSET TURNOVER (A/Assets)[4]	70.4%		73.4%		
G. NET RETURN ON ASSETS ((D + 14c + 18 + 20)/Assets)[4]	1.36%		3.10%		

[1] Replacements purchased

[2] Includes costs and investment associated with heat abatement

[3] Per cow value for cross ventilated facility minus per cow value for natural ventilation facility.

[4] Assets equal total value of breeding herd and land, buildings, and equipment.

Table 2. Return on Assets (Line G) versus Production and Facility Investment -- NatVent

Milk	Total investment in facilities and equipment, $/lactating cow*						
production	$4,737	$4,987	$5,237	**$5,487**	$5,737	$5,987	$6,237
21,500	0.23%	-0.08%	-0.38%	-0.65%	-0.91%	-1.15%	-1.38%
21,750	0.60%	0.27%	-0.03%	-0.32%	-0.58%	-0.83%	-1.07%
22,000	0.97%	0.63%	0.32%	0.02%	-0.26%	-0.52%	-0.76%
22,250	1.34%	0.99%	0.66%	0.36%	0.07%	-0.20%	-0.46%
22,500	1.71%	1.35%	1.01%	0.69%	0.39%	0.11%	-0.15%
22,750	2.08%	1.71%	1.36%	1.03%	0.72%	0.43%	0.16%
23,000	2.45%	2.07%	1.70%	**1.36%**	1.05%	0.75%	0.46%
23,250	2.82%	2.42%	2.05%	1.70%	1.37%	1.06%	0.77%
23,500	3.19%	2.78%	2.40%	2.04%	1.70%	1.38%	1.08%
23,750	3.56%	3.14%	2.74%	2.37%	2.02%	1.69%	1.38%
24,000	3.94%	3.50%	3.09%	2.71%	2.35%	2.01%	1.69%
24,250	4.31%	3.86%	3.44%	3.04%	2.67%	2.33%	2.00%
24,500	4.68%	4.22%	3.78%	3.38%	3.00%	2.64%	2.31%

* Investment per cow in herd equals investment per lactating cow times 84.7%.

** Costs vary by production level due to varying feed and hauling and promotion costs.

Table 3. Return on Assets (Line G) versus Production and Facility Investment -- LPCV

Milk	Total investment in facilities and equipment, $/lactating cow*						
production	$4,737	$4,987	$5,237	**$5,487**	$5,737	$5,987	$6,237
22,500	2.10%	1.73%	1.38%	1.05%	0.74%	0.44%	0.17%
22,750	2.48%	2.09%	1.73%	1.39%	1.07%	0.77%	0.48%
23,000	2.86%	2.46%	2.08%	1.73%	1.40%	1.09%	0.79%
23,250	3.24%	2.82%	2.44%	2.07%	1.73%	1.41%	1.11%
23,500	3.62%	3.19%	2.79%	2.41%	2.06%	1.73%	1.42%
23,750	3.99%	3.55%	3.14%	2.76%	2.39%	2.05%	1.73%
24,000	4.37%	3.92%	3.49%	**3.10%**	2.73%	2.38%	2.05%
24,250	4.75%	4.28%	3.85%	3.44%	3.06%	2.70%	2.36%
24,500	5.13%	4.65%	4.20%	3.78%	3.39%	3.02%	2.67%
24,750	5.50%	5.01%	4.55%	4.12%	3.72%	3.34%	2.98%
25,000	5.88%	5.38%	4.91%	4.47%	4.05%	3.66%	3.30%
25,250	6.26%	5.74%	5.26%	4.81%	4.38%	3.98%	3.61%
25,500	6.64%	6.11%	5.61%	5.15%	4.72%	4.31%	3.92%

* Investment per cow in herd equals investment per lactating cow times 84.7%.

** Costs vary by production level due to varying feed and hauling and promotion costs.

Table 4. Returns over Total Costs per Cow (Line D) versus Production and Facility Investment -- NatVent

Milk	Total investment in facilities and equipment, $/lactating cow*						
production	$4,737	$4,987	$5,237	**$5,487**	$5,737	$5,987	$6,237
21,500	-$463.21	-$492.22	-$521.23	-$550.24	-$579.25	-$608.25	-$637.26
21,750	-$441.39	-$470.40	-$499.41	-$528.42	-$557.43	-$586.44	-$615.44
22,000	-$419.57	-$448.58	-$477.59	-$506.60	-$535.61	-$564.62	-$593.62
22,250	-$397.75	-$426.76	-$455.77	-$484.78	-$513.79	-$542.80	-$571.81
22,500	-$375.93	-$404.94	-$433.95	-$462.96	-$491.97	-$520.98	-$549.99
22,750	-$354.12	-$383.12	-$412.13	-$441.14	-$470.15	-$499.16	-$528.17
23,000	-$332.30	-$361.30	-$390.31	**-$419.32**	-$448.33	-$477.34	-$506.35
23,250	-$310.48	-$339.49	-$368.49	-$397.50	-$426.51	-$455.52	-$484.53
23,500	-$288.66	-$317.67	-$346.67	-$375.68	-$404.69	-$433.70	-$462.71
23,750	-$266.84	-$295.85	-$324.86	-$353.86	-$382.87	-$411.88	-$440.89
24,000	-$245.02	-$274.03	-$303.04	-$332.05	-$361.05	-$390.06	-$419.07
24,250	-$223.20	-$252.21	-$281.22	-$310.23	-$339.23	-$368.24	-$397.25
24,500	-$201.38	-$230.39	-$259.40	-$288.41	-$317.42	-$346.42	-$375.43

* Investment per cow in herd equals investment per lactating cow times 84.7%.

** Costs vary by production level due to varying feed and hauling and promotion costs.

Table 5. Returns over Total Costs per Cow (Line D) versus Production and Facility Investment -- LPCV

Milk	Total investment in facilities and equipment, $/lactating cow*						
production	$4,737	$4,987	$5,237	**$5,487**	$5,737	$5,987	$6,237
22,500	-$350.39	-$379.40	-$408.41	-$437.41	-$466.42	-$495.43	-$524.44
22,750	-$328.21	-$357.21	-$386.22	-$415.23	-$444.24	-$473.25	-$502.26
23,000	-$306.02	-$335.03	-$364.04	-$393.05	-$422.06	-$451.06	-$480.07
23,250	-$283.84	-$312.85	-$341.85	-$370.86	-$399.87	-$428.88	-$457.89
23,500	-$261.65	-$290.66	-$319.67	-$348.68	-$377.69	-$406.70	-$435.71
23,750	-$239.47	-$268.48	-$297.49	-$326.50	-$355.50	-$384.51	-$413.52
24,000	-$217.29	-$246.30	-$275.30	**-$304.31**	-$333.32	-$362.33	-$391.34
24,250	-$195.10	-$224.11	-$253.12	-$282.13	-$311.14	-$340.15	-$369.15
24,500	-$172.92	-$201.93	-$230.94	-$259.94	-$288.95	-$317.96	-$346.97
24,750	-$150.74	-$179.74	-$208.75	-$237.76	-$266.77	-$295.78	-$324.79
25,000	-$128.55	-$157.56	-$186.57	-$215.58	-$244.59	-$273.59	-$302.60
25,250	-$106.37	-$135.38	-$164.38	-$193.39	-$222.40	-$251.41	-$280.42
25,500	-$84.18	-$113.19	-$142.20	-$171.21	-$200.22	-$229.23	-$258.24

* Investment per cow in herd equals investment per lactating cow times 84.7%.

** Costs vary by production level due to varying feed and hauling and promotion costs.

Figure 3.

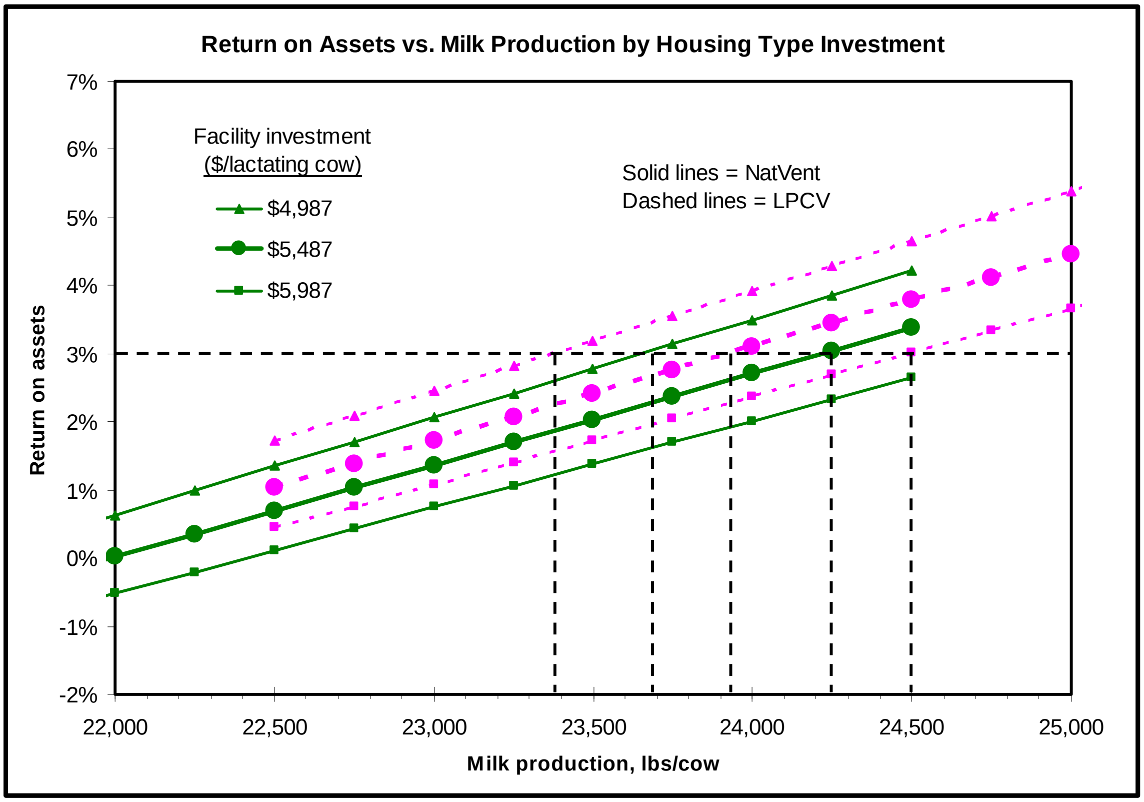
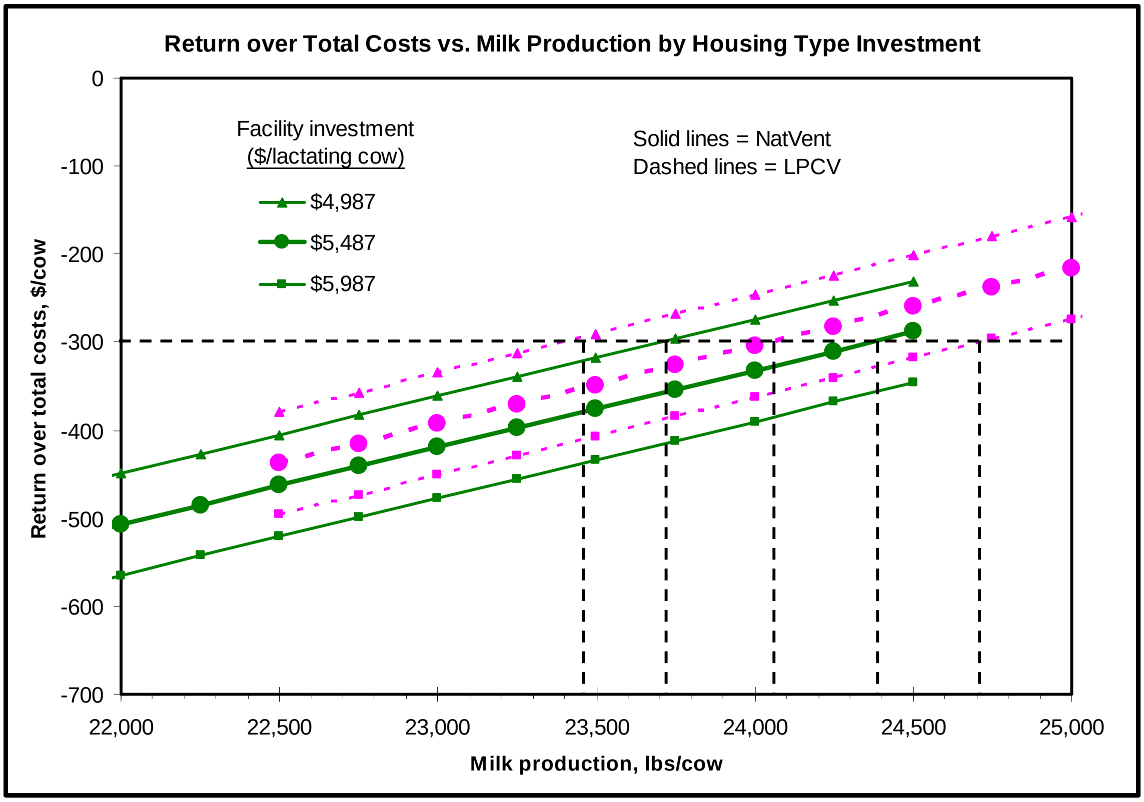


Figure 4.



Special Design Considerations

J. P. Harner and J. F. Smith, Kansas State University

Traditional housing systems for dairy cows and low profile cross ventilated buildings have many similarities. Stall width and length, concrete groove spacing, parlor type, milk storage tanks, and manure storage systems are the same with either housing system.

However, because LPCV buildings are uniquely designed, specific considerations are necessary to ensure optimum efficiency and cow comfort. The following is an easy-to-use reference list of a majority of decisions unique to LPCV buildings. This list is intended to provide quick facts and simple considerations to help in the LPCV design process.

Building Width & Number of Rows (assumes 2 rows of stalls per pen)

- 8 row – nominal width of 200 ft
- 10 row – nominal width of 250 ft
- 12 row – nominal width of 300 ft
- 16 row – nominal width of 400 ft

Interior Service Lanes

- Use to provide access for fan and cooling system maintenance
- Lane located along the inside of the building sidewalls
- 3 to 10 feet – minimum recommended with is 3 ft.
- Increases building width 6 to 20 feet

End Wall Doors & Extra Building Length (doors required per 200 ft wide building)

- 20 doors - one per alley on both ends of the building
    - 5 to 10 ft at each end or 10 to 20 ft extra building length
- 12 doors - 10 doors at one end and 2 doors on the feed lanes on the opposite end
    - 5 ft at end with 10 doors and 30 ft at the end with 2 doors, 35 ft extra in building length
- 4 doors - one per feed lane on both ends of the building
    - 30 ft lanes on both ends of the building 60 ft extra building length
- 3 doors – one per feed lane on one end and 1 door on the opposite end.
    - 30 ft at one end and 50 ft at other end or 80 ft extra building length
- 1 door – one at the end of one feed lane
    - 50 ft at each end or 100 ft extra building length

Building Overhang

- Needs to extend far enough to protect fans from snow and ice damage sliding off the roof
- Manufacturer’s fan specifications include information on length of fan shroud or hood.

Building Orientation (Preferred)

- Evaporative Pad Cooling System: north to south with pads on west and fans on east
- High-Pressure Mist System: east to west with fans on north and inlet on south
- Low-Pressure System: east to west with fans on north and inlet on south
- No evaporative cooling system (feed line soakers) - east to west with fans on north and inlet on south

Stall Configuration

Head to head or tail to tail has to be determined before the building can be ordered. The manufacturer will determine post spacing and location after decision is made. This is non-changeable after the building has been ordered.

Baffles

- Static pressure will determine number and height of baffles!!
- Desired air speed and building width have to match up
- Baffle Type: hard (metal), soft (curtain), or none
- Baffle Opening Size: based on the number of baffles
- Location of baffles

Winter Ventilation

- Type of Inlet
- Minimum air speed or minimum number of fans running
- Minimum inlet opening
- Management of snow events

Evaporative Cooling System

- Evaporative pads
- High-pressure mist
- Low-pressure nozzles
- None –feed line soakers only

Feed Alley Width

- 16 to 20 ft – some use a narrow width to reduce overall building width
- 18 ft is the minimum recommendation

Parlor ventilation and Cooling System

- Type: natural, tunnel, or cross ventilated
- Holding pen cooling, evaporative or soakers

Parlor Transfer Lanes and Locations

- Two or one way traffic
- Parlor exit lanes have to be sized to hold 50 % of a pen
- Usually only one 20 to 30 ft wide travel lane

Insulation

- Type: spray-on, fiberglass batt, rigid board, or none
- Close-cell spray-on is recommended
- R-value of insulation: minimum R-6 recommended

Lighting

- Light level: 25 foot candles is the minimum recommendation
- Light type: fluorescent or low bay metal halide
- Light strategy for lactating cows: 16 hours of light with 8 hours of dark, or 24 hours of light

- Light strategy for dry cows: 8 hours of light with 16 hours of dark
- Night light level, recommend 5 foot candles or less
- Automated or manual light control

Water System

- Water treatment system
- Emergency back-up water supply
- Pumping of water hydrants along interior service lanes

Exhaust Fans

- Automatic or manual control
- Diameter, horsepower
- Operating static pressure

Back-up Generator

- Parlor and milk cooling equipment
- 50 % of fans –
    - Fans must be wired to allow 3 to 5 fans to turn on and come up to operating speed before more fans are turned on -- must work with suppliers of generator and electrical control panel to work out the emergency power fan start up procedures prior to installation of fans.

Dry Cows/ Special Needs / Treatment Area

- Extra pens and treatment space in the same housing area as lactating cows or a separate area designated for dry cows and treatment
- Offset area adjacently attached to the parlor or separate building

Number of Milking Groups

- 8 to 12 groups, interrelated with manure management

Manure Handling Procedure

- Method: scrape, flush, or vacuum
- Time required for manure removal if scraping or using the vacuum system versus milking cows

Upper Management Issues

- Understanding of fan static pressure and the relationship between operating fans and the inlet area – seasonal differences in ventilation
- Organization of task to prevent doors from being open constantly
- Understanding of water treatment system
- Management of employees in an artificial light environment
- Maintenance issues of doors and lights