In the Thermoneutral Zone: Potential Benefits of LPCV Buildings

Joseph P. Harner
Extension Engineer, Livestock & Grain Systems
Kansas State University
Bio & Ag Engineering
Seaton Hall 147
Manhattan, KS 66506-2917
Office - 785-532-2930
Fax - 785-532-6944
J.F. Smith,
B. J. Bradford,
M.W. Overton,
K.C. Dhuyvetter

Introduction

Low profile cross ventilated (LPCV) freestall buildings provide a temperate environment that ranges within a dairy cow's thermoneutral zone even during summer and winter months. LPCV buildings typically maintain an air temperature 8-15°F cooler than ambient during the summer, but the relative humidity is often 75% or greater due to evaporative cooling and moisture generated by cows. In the winter the interior of an LPCV building is 10-30°F warmer than outside air temperatures.

The ability to control a cow's environment increases milk production, improves feed efficiency, raises income over feed cost, strengthens reproductive performance, allows for controlled lighting, reduces lameness, and lessens fly-control costs. The benefits of LPCV buildings may be examined by reviewing scientific literature and understanding improvements that are possible when an environment complements a cow's thermoneutral zone.

Environmental Impact on Nutrient Requirements and Efficiency

Dairy cows that are housed in an environment outside their thermoneutral zone alter their behavior and physiology in order to adapt. Adaptations are necessary to maintain a stable core body temperature, but nutrient utilization and profitability are negatively affected.

The upper critical temperature, or upper limit of the thermoneutral zone, for lactating dairy cattle is approximately 70-80°F for maximum nutritional benefits (NRC, 1981). When temperatures exceed the recommended range, cows 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 a 100°F environment decreases milk production by 50% or more as compared to thermoneutral conditions (Collier, 1985).

Relatively little research has been done on the effect of cold stress on lactating dairy cattle. The high metabolic rate of dairy cows makes them 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, evidence shows that the performance of lactating cows decreases at temperatures below 20°F (NRC, 1981).

One clear effect of cold stress is increased feed intake. While greater 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 digestion time and results in less digestion as temperatures drop (NRC, 2001). Cows also maintain body temperature in cold environments 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 hurts dairy profitability.

Smith et al (2008) assessed the effects of environmental stress on feed efficiency and profitability. He used a model which incorporated the temperature effects on dry matter intake, diet digestibility, maintenance requirements, and milk production. Figure 1 shows the expected responses of a cow producing 80 pounds of milk per day in a thermoneutral environment. 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. With these research results, cost benefits could be estimated for environmental control of LPCV facilities.

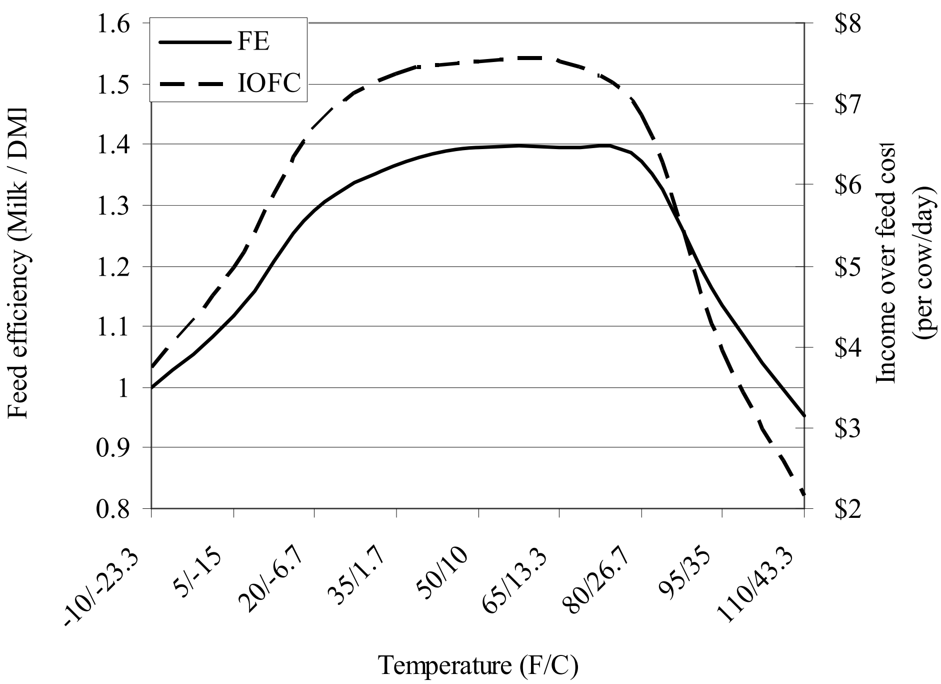

Figure 1: Responses to Environmental Stress (thermoneutral production of 80 lbs/day, MR Cost of $0.12/lb dry matter, and milk value of $18/cwt)

Environmental Impact on Reproduction

Even though cold stress has little effect on reproduction, heat stress reduces libido, fertility, and embryonic survival in dairy cattle. Environmental conditions above a dairy cow's thermoneutral zone decrease the ability to dissipate heat and result in an increased core body temperature. The elevated body temperatures negatively impact reproduction for both 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 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.). As milk production and feed intake increase, a greater internal heat load is produced and the impact of heat stress on reproduction is dramatic (al-Katanani et al., 1999).

Whether the decline in pregnancy rates is voluntary or not, a fewer number of pregnant cows creates holes in the calving patterns. In the fall an increased number of cows often become pregnant and, consequently, place additional pressures on the transition facilities nine months later when an above-average group of cows must move 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.

Creating a Thermoneutral Zone Housing Environment

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. Evaporative cooling is often used to cool LPCV buildings, and Harner and Smith (2008) discuss specific design details of the buildings when this cooling method is utilized. 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 2. Cooling potential is the maximum temperature drop possible, assuming the evaporative cooling system is 100% efficient. The cooling potential is greater as air temperature increases and relative humidity decreases. Evaporative cooling systems perform better as the humidity decreases below 50 percent.

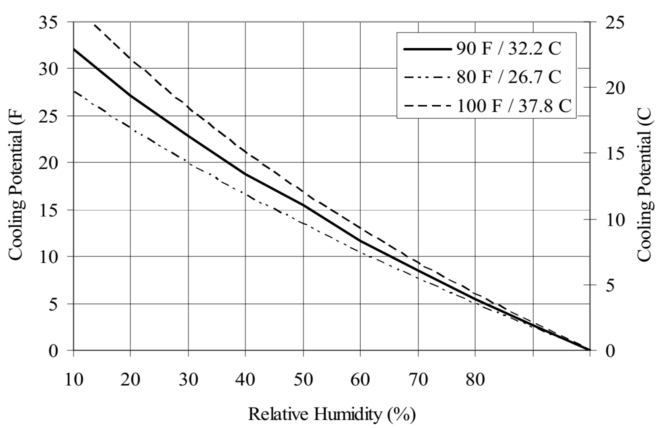

Figure 2: Impact of Relative Humidity and Temperature on Cooling Potential with an Evaporative Cooling System

The cooling potential is a function of the air's ability to absorb moisture. Additional moisture in the air decreases the air temperature and increases humidity. Theoretically, the lowest possible air temperature occurs when the air is at 100% humidity, or saturation. Most designers assume the air temperature exiting an evaporative cooling system is reached when the air has absorbed 75% of the moisture possible between inlet conditions and saturation. Since the outdoor air temperature constantly changes, the exhaust temperature from an evaporative cooling system also changes.

LPCV buildings range in width from 200-500 feet, and the number of rows or freestalls vary from 8-24, depending on the building width. The targeted air exchange rate through the buildings is 120 seconds or less, but buildings wider than 300 feet have exchange rates of 180-240 seconds\

Different management strategies for environmental control are used during cold weather. The first mode decreases the air exchange rate by turning off fans in order to prevent frozen manure on the alleys. This strategy prevents potential lameness and injury problems but leads to a potential increase in ammonia and moisture levels inside the building. The second management strategy utilizes a controller to operate fans along the inlet side of the building. The disadvantage of this mode is that as the outdoor air temperature declines, the number of operating fans remains constant. As a result, cold temperatures are maintained inside the building, manure freezes in alleys near the inlet, and employees are exposed to very cold temperatures. Research indicates that an 8-minute air exchange is the recommended maximum air exchange rate.

Though the interior of a LPCV building closely resembles a naturally ventilated freestall (Harner and Smith, 2008), LPCV buildings incorporate baffles to divert air flow into the stall area. Depending on the number of baffles, air speed in the stall area is increased from 2-3 miles per hour (mph) to 6-8 mph during the summer months. Dairies that utilize baffles observe better lay-down rates of cows and report a corresponding increase in milk production.

Results of Environmental Studies in LPCV Buildings

Table 1 summarizes the temperature rise across LPCV buildings in the upper Midwest from July 17 to August 16, 2007. A temperature increase of 0.85 ^{o}F per 100 feet of building width was observed. Since the humidity in the building was high due to the evaporative cooling system, approximately a 1 unit increase in the temperature humidity index (THI) existed per 100 feet of building width.

Table 2 compares the average, maximum and minimum ambient temperatures with the interior conditions of a 400-foot wide LPCV building in Iowa. The average ambient temperature and relative humidity from July 17 to August 16, 2007, was 77°F and 77%, respectively. The average temperature inside the LPCV building was approximately 3°F cooler than ambient, but the maximum temperature was 85°F as compared to the outside temperature of 96°F. The ambient temperatures were 77°F or greater for over 50% of the study. However, when measured near the exhaust fans of the LPCV building, the ambient temperature was greater than 77°F only 28% of the time. Also, the ambient temperatures were less than 68°F only 7% of the time, as compared to 12% inside the LPCV building. However, during the night, the indoor temperatures increased because the evaporative cooling pad was turned off to allow the pad to dry and prolong pad usage.

Table 1: Average Temperature Rise Between Baffles and Per Foot of Building Width

Dairy ID	Nominal Building Width ft	Average Temperature (^oF) Rise/Foot of Building Width*
# 1	400	0.0085 °F/ft
# 2	400	0.0077 °F/ft
# 3	520	0.0110 °F/ft
# 4	300	0.0095 °F/ft
# 5	250	0.0057°F/ft
Average		0.0085 °F/ft

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

Table 2: Comparison of Ambient and Interior Temperatures

	Ambient	Inlet Baffle	Middle Baffle	Exhaust Baffle
Average Temperature (°F)	77	73	74	74
Maximum Temperature (°F)	96	85	83	85
Minimum Temperature (°F)	58	58	59	58
Percent of Hours at 77 °F or above	52	21	24	28
Percent of Hours Between 68 to 77 °F	41	67	66	60
Percent of Hours Below 68 °F	7	12	10	12

Figure 3 illustrates the average ambient, inlet and exhaust temperatures in a 400-foot wide LPCV building in Iowa from July 17 to August 16, 2008.

Temperature data was also logged during the winter of 2008. The data was averaged by hour and baffle location from January 18 to February 17, 2008, as shown in Figure 4. The ambient temperature during the winter period averaged 20 °F colder than barn conditions. Figure 4 shows a rapid warming of the air between the inlet and first baffle in two LPCV facilities, and the air continued to warm until exhausted from the building. Figure 4 also shows the exhaust air temperature as a function of inlet (outdoor) air temperature. As the outdoor air temperature decreased, the variability in exhaust temperature increased. The exhaust air temperature was 25-45°F when the inlet air temperature was -5^{o}F. The variability is attributed to a difference in air exchange rates because air temperature is lower at the exhaust as the air exchange rate increases

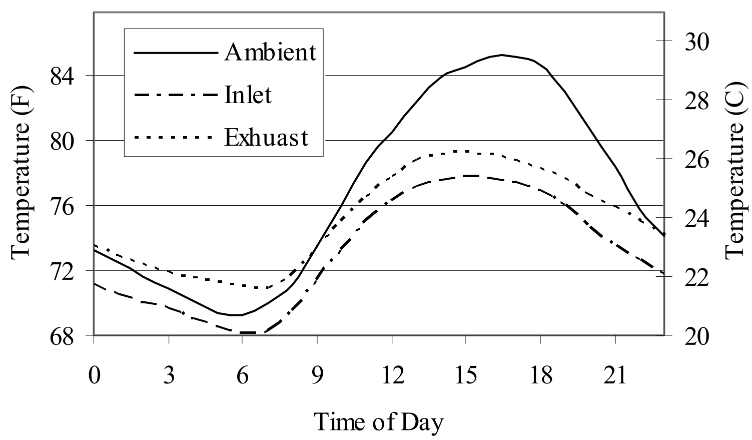

Figure 3: Comparison of Ambient, Inlet and Exhaust Temperatures

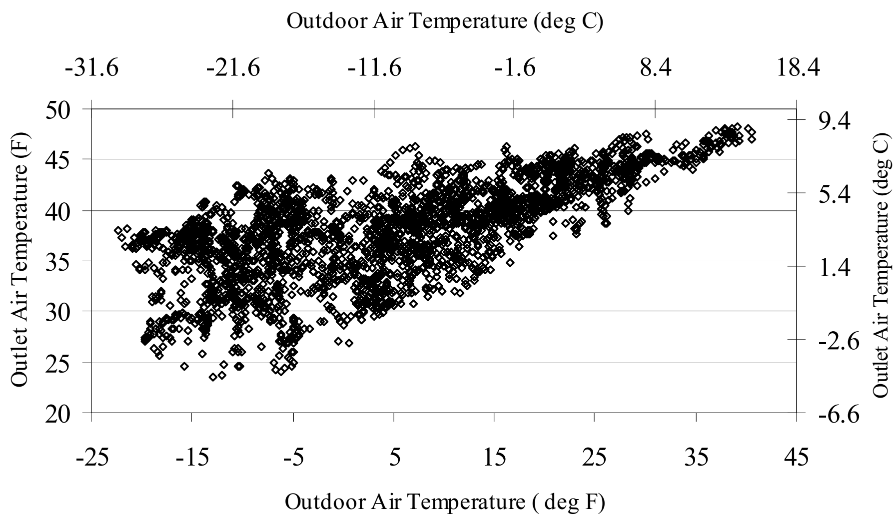

Figure 4: Relationship Between Outdoor Air Temperatures and Outlet (Exhaust) Air Temperatures in a 400-foot wide LPCV building

Figure 5 shows a correlation between the outdoor air temperature and the temperature rise across an LPCV building in Minnesota during the winter of 2008. Temperature rise is defined as the difference between the exhaust and outdoor air temperature. Less variability exists in the temperature rises above 20°F since there are more consistent strategies in fan operation and less concern about freezing alleys.

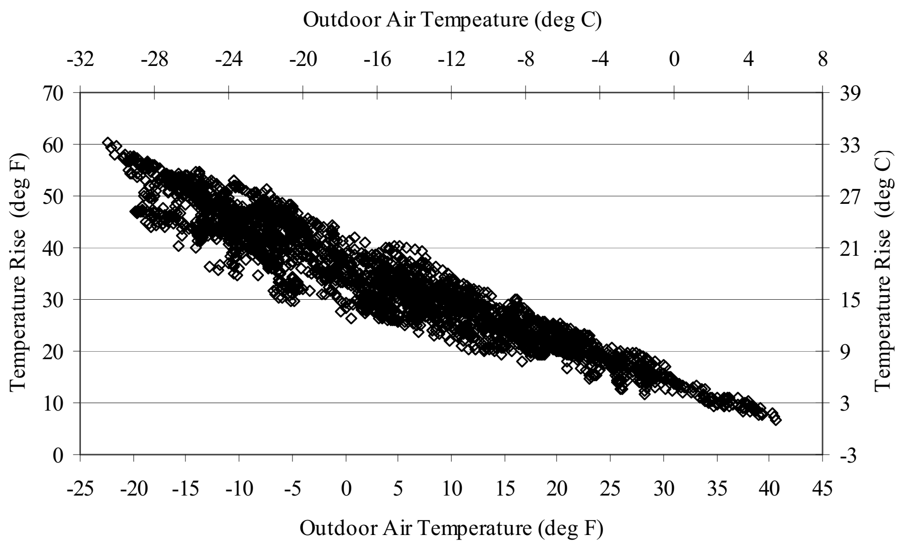

Figure 5: Outdoor Air Temperatures and Temperature Rise in a 500-foot wide building

Figure 6 illustrates the average hourly temperatures from January 18 to February 17, 2008, inside two 400-foot wide LPCV buildings in the upper Midwest. The difference in temperature rise from the inlet to the exhaust is explained by different stocking densities and air exchange rates.

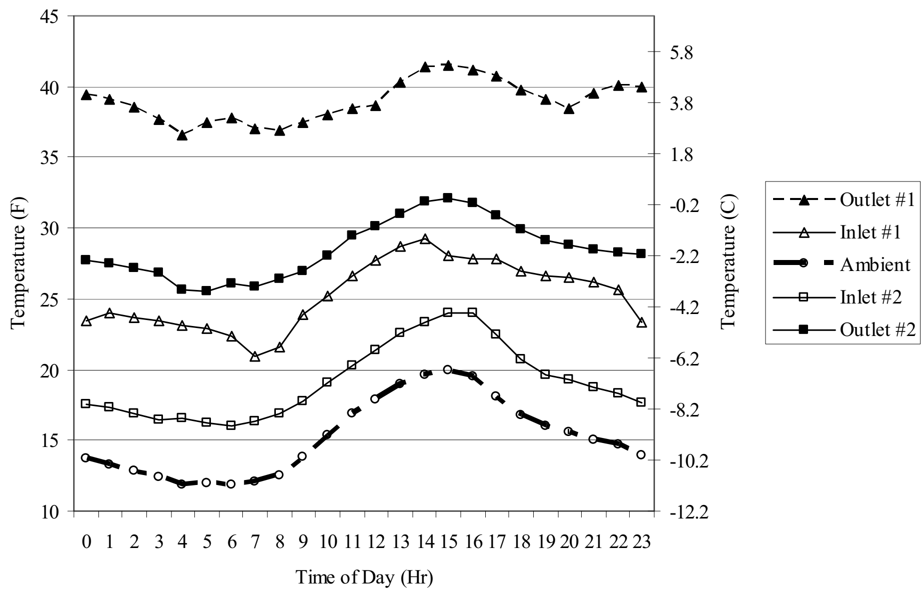

Figure 6: Summaries of Temperatures in LPCV Buildings

Impact of Geographical Location

Table 3 provides annual hours when the ambient temperatures is within °5F increments for various dairy locations in the United States. The data was obtained from a military base near the selected locations. Dairy cows experience more hours of ambient temperatures below their lower thermoneutral zone limit (20°F) when housed on dairies in northern states and more hours of ambient temperatures above their upper thermoneutral zone limit (70°F) when housed on dairies in southern states.

Figure 7 shows that ambient temperatures are within the thermoneutral zone 65-78% of the time for a majority of major dairy locations in the United States. The exceptions are Gainesville, FL and Phoenix, AZ where the ambient temperatures are within the thermoneutral zone only 50% of the year. Yearly ambient conditions result cows being exposed to heat stress, cold stress or both 25% of the year.

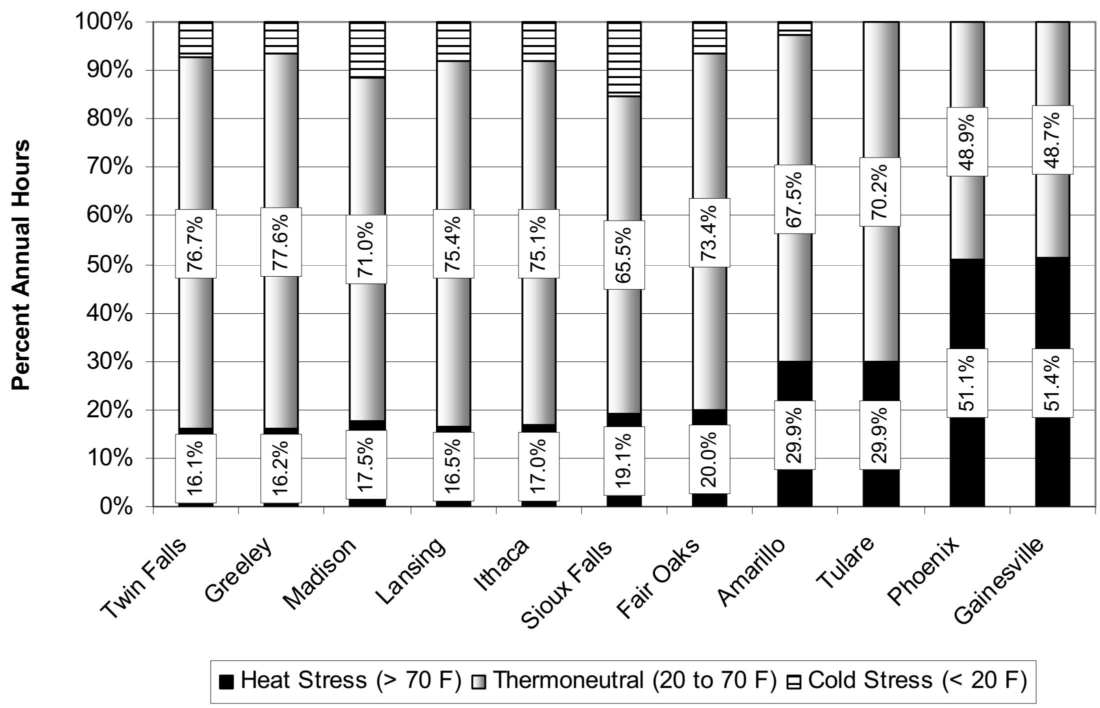

Figure 7: Percentage of Annual Ambient Hours in the Thermoneutral Zone of Dairy Cows

Figure 8 shows the potential benefits of LPCV buildings. The housing environment may be efficiently maintained within the cow's thermoneutral zone 85-93% of the time. The evaluation is based on temperature only so, with evaporative cooling and low relative humidity in Phoenix, AZ, the percentage of hours within the thermoneutral zone could be greater than 65 percent. Research shows that, regardless of location, LPCV buildings increased the annual number of hours the housing environment measured within a cow's thermoneutral zone by 17 percent

Table 3: Annual Hours in 5°F Increments for Dairy Locations in the United States

	Tulare, CA (Merced, CA)	Twin Falls, ID (Pocatello, ID)	Greely, CO (Denver, CO)	Sioux Falls, SD (Sioux Falls, SD)	Madison, WI (Madison, WI)	Lansing, MI (Lansing, MI)	Fair Oaks, IN (South Bend, IN)	Ithaca, NY (Syracuse, NY)	Gainesville, FL (Jacksonville, FL)	Amarillo, TX (Amarillo, TX)	Phoenix, AZ (Glendale, AZ)
>100	62			2						9	517
95-99	159	21	7	20	6	2	5	3	38	88	463
90-94	287	99	71	92	42	27	51	28	276	258	592
85-89	364	206	174	182	137	115	159	120	579	385	709
80-84	457	285	291	310	287	261	324	265	810	485	753
75-79	581	352	384	463	451	411	504	441	1229	602	730
70-74	707	443	494	598	605	626	707	628	1563	790	710
65-69	804	518	618	661	689	731	761	731	987	852	759
60-64	965	582	794	664	726	734	718	718	867	766	801
55-59	1100	653	776	593	639	675	610	709	702	670	801
50-54	1098	683	739	532	548	601	588	666	633	667	725
45-49	902	705	729	508	523	578	562	628	440	634	573
40-44	681	776	752	504	510	574	585	633	318	615	378
35-39	397	852	724	572	631	701	711	723	187	592	179
30-34	159	885	704	668	827	859	860	812	94	533	57
25-29	32	637	555	563	663	687	615	554	28	369	7
20-24	1	419	394	465	458	452	409	400	6	205	1
15-19		250	243	394	314	314	241	292		127	
10-14		164	137	277	247	190	164	200		58	
5-9		105	84	238	179	115	87	113		28	
< 5		115	98	442	276	102	95	90		15	

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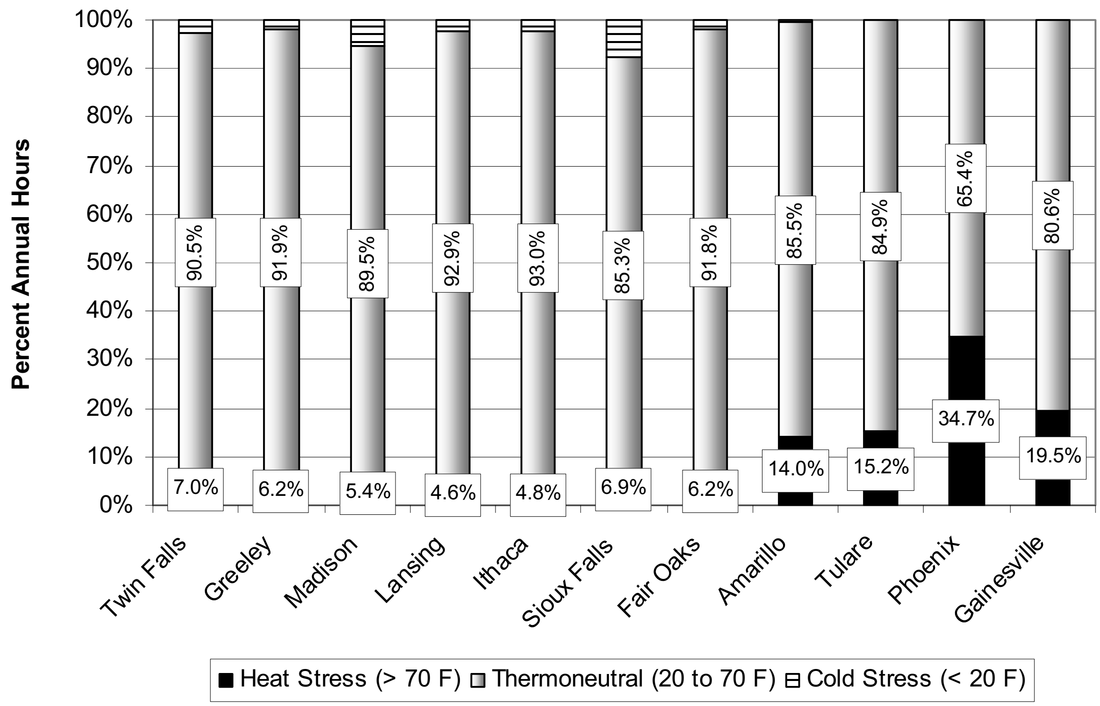

Figure 8: Impact of LPCV Freestall Housing on Percentage of Annual Hours in the Thermoneutral Zone

Table 4 compares the weather conditions from February 1-15, 2008, at different locations. Except for Sioux Falls, SD, the ambient temperature was above the lower limit of the thermoneutral zone 65-75% of the study for dairies in the northern states. Dairy cows in the southern states did not experience cold stress during this period.

Table 5 compares the weather conditions from August 1-15, 2008, at different locations. Except for Ithaca, NY, the ambient temperature exceeded the upper limit of the thermoneutral zone at least 65% of the time for dairies in the northern states.

Table 4: Hours When Ambient Temperature Was Less than Lower Limit (20°F) of Thermoneutral Zone

	Dairy Locations Arranged Based on Coldest to Warmest Average Temperature (F) From Feb 1-15, 2008									
	Sioux Falls SD	Ithaca, NY	Madison, WI	Lansing, MI	Fair Oaks, IN	Twin Falls, ID	Amarillo, TX	Tulare, CA	Phoenix, AZ	Gainesville, FL
	Ambient Temperatures (F)									
Average (F)	13.3	27.1	19.7	23.7	26.1	31.8	42.3	47.7	53.4	60.1
Maximum (F)	30	50	35	45	49	48	69	68	76	83
Minimum (F)	-9	1	-9	-3	0	14	17	30	35	29
Temperature Range	Hours within Temperature Range									
> = 20 F	105	277	220	241	248	335	331	335	335	335
10 to 20 F	109	29	42	45	55	0	4	0	0	0
<10 F	122	30	73	49	32	0	0	0	0	0
Temperature Range	Percentage of Hours within Temperature Range									
> = 20 F	31.3	82.5	65.7	72.0	74.1	100	98.8	100	100	100
10-20 F	32.4	8.6	12.5	13.4	16.4	0	1.2	0	0	0
<10 F	36.3	8.9	21.8	14.6	9.6	0	0	0	0	0

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Table 5: Hours When Temperature Exceeded Upper Limit (70°F) of Thermoneutral Zone

	Dairy Locations Arranged Based on Coldest to Warmest Average Temperature (F) From Feb 1-15, 2008									
	Sioux Falls SD	Ithaca, NY	Madison, WI	Lansing, MI	Fair Oaks, IN	Twin Falls, ID	Amarillo, TX	Tulare, CA	Phoenix, AZ	Gainesville, FL
	Ambient Temperatures (F)									
Average (F)	73.1	65.1	69.5	68.3	72.3	75.4	77.4	81.3	94.5	80.1
Maximum (F)	91	81	87	86	91	96	94	104	112	94
Minimum (F)	57	49	51	49	56	57	58	58	77	70
Temperature Range	Hours within Temperature Range									
> = 70F	213	97	177	158	215	216	249	266	336	336
<70 F	123	239	159	178	121	120	87	70	0	0
Temperature Range	Percentage of Hours within Temperature Range									
> = 70 F	63.4	28.9	52.7	47.0	64.0	64.3	74.1	79.2	100	100
<70 F	36.6	71.1	47.3	53.0	36.0	35.7	25.9	20.8	0	0

The THI of the ambient conditions is compared in Table 6. The THI exceeded 70 over a range of 12-100% from August 1-15, 2008, depending on geographical location. Assuming the evaporative cooling system was 100% efficient, the percentage of time at most of the locations was less than 5%, with the exception of Fair Oaks, IN and Gainesville, FL which experienced high relative humidity.

Table 6: Hours When THI Equalled 70 or Greater

	Dairy Locations - August 1 – 15, 2008									
	Sioux Falls SD	Ithaca, NY	Madison, WI	Lansing, MI	Fair Oaks, IN	Twin Falls, ID	Amarillo, TX	Tulare, CA	Phoenix, AZ	Gainesville, FL
	Ambient Temperature Humidity Index									
Average THI	70.3	63.8	67.3	65.9	69.4	68.4	71.5	72.3	80.7	76.9
Maximum THI	83.6	75.6	78.7	78.4	83	79.5	79.1	83.8	85.6	84.1
Minimum THI	57	49	51.4	49.5	56	57.3	58	58	73.6	69.1
	Hours when THI => 70 (336 maximum number of hours)									
Ambient Conditions	192	41	132	114	178	137	208	207	336	328
Benefit of LPCV assuming 100 % efficiency	22	1	18	3	54	0	0	0	4	285
	Percentage of Hours THI => 70(336 maximum number of hours)									
Ambient Conditions	57.1	12.2	39.2	33.9	53.0	40.7	61.9	61.6	100	97.6
Benefit of LPCV assuming 100 % efficiency	6.5	0.3	5.4	0.9	16.1	0	0	0	1.2	84.8

Summary

LPCV facilities are able to minimize fluctuations in core body temperature by providing an environment which closely resembles a cow's thermoneutral zone.

- Heat stress and cold stress significantly decrease income over feed cost. Limiting environmental stress throughout the year increases feed efficiency.
- Temperatures inside a LPCV building with evaporative cooling are 8-15°F cooler than ambient temperatures during afternoon hours.
- Temperatures inside a LPCV building during the winter months are 15-30°F warmer than ambient temperatures, depending on the air exchange rate.

- Improving a cow's environment greatly reduces the impact of heat stress on present and future milk production.

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