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# Barn Environment Study

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## Introduction

Cross-ventilated freestall (**CV**) and compost bedded pack (**CB)** dairy barns are newer dairy cattle housing options in the Upper Midwest. The first CV barn was built in North Dakota in 2005 and since that time several barns have been built in various areas of the United States. Cross-ventilated barns are generally a fully enclosed facility characterized by a low roof pitch of 0.5/12 and a warehouse-type structure (Smith and Harner, 2007). On the air intake side of the barn, evaporative cooling pads fill the wall and air is pulled through the pads by exhaust fans on the opposite side. Inside the barn, baffles are placed over the stalls to maintain airflow. Baffles are installed parallel to the feed alley to reduce equipment interference (Sheffield et al., 2007).

The CV barns use evaporative cooling for heat abatement during the warmer months. Evaporative cooling in tunnel ventilated dairy facilities resulted in reduced respiration rates, lower rectal temperatures, improved pregnancy rates, reduced days open, and higher milk productions compared to other heat abatement strategies (Ryan et al., 1992; Smith et al., 2006). In addition, CV barns have reduced footprint compared to conventional freestall barns, cows walk shorter distances to the milking parlor, and they offer better barn environmental control (Harner et al., 2007).

The first CB barn was built in Minnesota in 2001 (Barberg et al., 2007a). This barn is typically built for improved cow comfort by removing the lying restrictions of standard stalls. The barn is characterized by a large, loose housing pack area that is separated from the feed alley by a 1.2 m-high wall. The pack is usually bedded with dry wood sawdust or other organic materials and tilled twice daily. Various types of equipment can be used for tilling, including cultivator, rotary tiller and chisel plow, and the depth of tilling is usually approximately 10 inches. Due to high cost and reduced availability of bedding materials these facilities are typically used for housing smaller herds of 50 to 200 cows or as a special needs barn in larger herds. Lameness prevalence in these barns was 7.8% (Barberg et al., 2007b) compared to a lameness prevalence of 25% in freestall barns (Espejo et al, 2006) and 20% in tie-stalls (Cook, 2003).

There has been limited research evaluating CV and CB housing systems. Therefore, the objectives of this cohort study were to describe the housing systems and assess air quality (aerial ammonia and hydrogen sulfide concentrations), air velocity, light intensity, temperature, and humidity in CV, CB and conventional naturally ventilated freestall (**NV**) barns. Naturally ventilated freestall barns were included as controls. In addition, we aimed to describe animal welfare using outcome based measurements (locomotion, body condition, hygiene, hock lesions, respiration rates, turnover, mortality, and mastitis prevalence) in CV and CB barns compared to NV barns.

The study was conducted on 18 commercial dairy farms, six of each housing type, in Minnesota and eastern South Dakota. Each farm was visited once in each season. Approximately 93% of all animals in each pen were visually scored each visit. One observer scored cows for locomotion on a 1 to 5 scale, with 1=normal locomotion, 2=imperfect locomotion, 3=lame, 4=moderately lame, and 5=severely lame. Another observer scored cows for body condition on a 1 to 5 scale, with 1=thin and 5=obese. The final observer scored cows for hygiene (on a 1 to 5 scale with 1=clean and 5=severely dirty) and hock lesions (1=no lesion, 2=mild lesion or hair loss, and 3=swollen hock or severe lesion). Barn temperatures were measured every hour using a data logger. Dairy farms were matched as closely as possible by geographical location and herd size. Fifteen out of the 18 herds were on DHIA testing and on farm records were collected when available. For two of the three herds not on DHIA testing, on-farm milk weights were used for analysis. To reduce variation in hock lesion and lameness prevalence, all freestall barns used deep bedded sand stalls. In addition, freestalls were similar in size and design across facilities, with an average width of approximately 48 inches, length of 96 inches and neck rail height of 48 inches. Five of the six CB barns used dry wood sawdust as the primary bedding material and one barn used a wheat straw by-product.

## Results

### Aerial ammonia concentrations

Ammonia concentrations (ppm, LS Mean) were 3.9 for CB, 5.2 for CV, and 3.3 for NV barns. The CB barns had similar ammonia concentrations to the NV barns. The CV barns had greater concentrations than CB and NV barns ($P = 0.025$ and $P = 0.001$, respectively). Summer had the highest concentration of ammonia in all three housing systems. The CV barns had greater concentrations of ammonia than NV barns during the winter and spring seasons. The CB barns were not significantly different from CV or NV barns during that time. Concentrations during winter, spring, summer, and fall were 3.5, 4.0, 5.6, and 3.5, respectively. Summer had higher concentrations than winter, spring, and fall ($P < 0.001$). Spring ammonia concentrations were greater than fall and winter ($P = 0.003$ and $P = 0.009$, respectively). Winter concentrations were similar to fall. According to the National Institute for Occupation Safety and Health (NIOSH) ammonia exposure should not exceed 25 ppm in a 40-hour week (up to a 10-hour day). None of the farms in the study had concentrations reaching 25 ppm. The highest recorded ammonia concentration was 20 ppm during the fall in a CV facility.

### Hydrogen sulfide aerial concentrations

Hydrogen sulfide concentrations were (ppb, LS Mean) 13 for CB, 32 for CV, and 17 for NV barns. There were no differences between CB and NV barns for hydrogen sulfide concentrations. The CV barns had higher concentrations than CB and NV barns ($P < 0.001$ and $P = 0.021$, respectively). Hydrogen sulfide concentrations were lowest during the fall (12 ppb) and spring (15 ppb), intermediate during the summer (18 ppb) and highest during the winter (41 ppb). The recommended exposure limit for hydrogen sulfide by the NIOSH is 10 ppm for a 10-hour work day in a 40-hour work week. The highest recorded hydrogen sulfide concentration was 0.82 ppm during the summer in a CV barn. No farm had hydrogen sulfide concentrations that were expected to interfere with the workers or the animals.

### Light intensity

Recommended light intensity for lactating dairy cattle over the feed bunk has ranged from 108 lux (10 foot candles; Dahl, 2001) to 215 lux (20 foot candles; Peters et al., 1978). Light intensity (lux) was 929 for CB, 118 for CV, and 430 for NV barns, respectively. Overall, CV barns had lower light intensity than CB and NV barns ($P < 0.001$). There were no differences between CB and NV barns. The CV barns had lower light intensity than CB and NV barns during each season except during the fall when it was not different from NV barns. The CV barns did not have the seasonal differences that the CB and NV barns experienced. The CB barns had the greatest light intensity during the summer and winter. Spring and fall did not differ in light intensity. The NV barns also had the greatest light intensity during the summer and winter, intermediate during the spring and lowest during the fall. Light intensity in CB and NV barns was mainly dependent on the outside conditions. Winter measurements were probably high due to the reflection off the snow. One set of fall measurements were taken during the dark in a NV barn and a CV barn and one winter measurement in a CV barn. Winter, spring, summer, and fall light intensities were 395, 343, 474, and 265 lux, respectively. Winter did not differ in light intensity from spring and summer. Fall light intensity was lower than spring, summer, and winter ($P = 0.002$, $P < 0.001$, $P = 0.025$, respectively). Summer light intensity was greater than spring ($P < 0.001$). The CV barns were below the recommended light intensity for dairy cows by the end of the study. We recommend that producers building CV barns consider installing additional lighting as bulb output decreases over time due to dust and lamp depreciation.

### Air velocity

Air velocity for the three housing systems were (m/s, LSMean) 0.7 for CB, 0.90 for CV, and 0.66 for NV barns, respectively. There were no differences in air velocity among the three housing systems except during the spring and summer months. The CV barns had greater air velocity than CB and NV barns during the spring ($P = 0.018$ and $P = 0.044$, respectively) with no differences between CB and NV barns. During the summer, CV barns had greater air velocity than CB barns ($P = 0.039$). There were no differences between NV and CB, and CV and NV barns for air velocity during the summer. Air velocities differed each season ($P < 0.001$). Winter had the lowest air velocity (0.34 m/s), intermediate were fall (0.70 m/s) and spring (0.96 m/s), and the highest air velocity was during the summer (1.12 m/s).

### Air temperature and relative humidity

The CB and the NV barns had high correlations (0.81-0.97) between inside barn temperature and ambient outside temperature, which would be expected with natural ventilation. The correlations in the CV barns were high during the spring, summer, and fall (0.84-0.90); however, they had warmer barn temperatures than outside during the winter which reduced the correlation to 0.62.

Barn and outside temperature-humidity index (**THI**) correlations were only used from the summer measurements since THI is a measurement of heat stress. Correlations were relatively high between barn and outside THI (0.93-0.95). Both NV and CB barns had greater THI than outside ambient. The CV barns were 0.5 THI units less than outside.

Overall barn temperatures were 47.1, 51.8, and 48.9°F in CB, CV, and NV barns, respectively. During the winter, CV barns (39.9°F) were significantly warmer than CB (25.2°F) and NV (28.8°F) barns ($P < 0.001$). The CV barns were warmer than CB and NV barns in the winter most likely due to reducing the number of fans running in the barn and having a fully enclosed and insulated structure.

To investigate whether CV barns were cooler than NV and CB barns during the warmest part of the summer, we performed an analysis with all outdoor temperatures less than 27°C excluded from the dataset. The THI in CV barns was 3.1 and 3.3 units lower than CB and NV barns, respectively ($P < 0.001$). However, all housing systems had THI greater than 72 which indicated that all cows were experiencing some heat stress.

### Bedding bacterial counts

Geometric means of bacterial counts (cfu/mL) from bedding cultures were 6,000; 31; 4,000,000; 2,000; and 197,000 cfu/mL for coliforms, *Klebsiella* (% of coliforms), environmental *Streptococcus*, *Staphylococcus* species, and *Bacillus*, respectively. There were no differences among the housing systems for coliform counts in the bedding; however, there was a seasonal effect with summer samples being higher than winter samples ($P$=0.002). This was also seen in NV barns where the coliform counts were greater in the summer ($P = 0.027$). There was a trend for *Klebsiella* counts to be higher in the summer than in the winter ($P = 0.10$). There were no differences between seasons or housing systems for environmental *Streptococcus*. There was a trend for higher counts of *Staphylococcus* species in CB barns than NV and CV barns ($P = 0.09$) and a trend for higher counts in the summer than the winter ($P = 0.09$). *Bacillus* counts were greater in summer than winter in CB barns ($P = 0.043$) with no differences between NV and CV barns.

### Lameness prevalence

Lameness prevalence was lower in CB (6.4%) than NV barns (17.7%; $P = 0.010$). There was a trend for CV prevalence (14.1%) to be greater than CB ($P = 0.08$) and it did not differ from NV barns. These results for CV and NV were similar to 17.1% for sand based freestalls (Espejo et al., 2006) and 7.8% for CB in Minnesota (Barberg et al., 2007b). Lameness prevalence by pens ranged from 0 to 43.3%, 0 to 60%, and 1.3 to 65.3% in CB, CV, and NV barns. We hypothesize that CB barns had lower lameness prevalence because cows in that system spend less time standing on concrete and don’t have restrictions when lying or rising. Size of the farm may also have some influence on lameness prevalence; CB barns were smaller operations where producers can probably more easily observe cows and identify lameness cases.

Lameness prevalence increased as parity increased. Primiparous pens had lower lameness prevalence than multiparous pens (17.0 vs. 8.5%; $P < 0.001$, respectively). There was a housing system by parity interaction. Lameness prevalence was greater for multiparous pens housed in NV barns than multiparous pens in CB barns ($P = 0.02$). There were no differences between multiparous pens in NV and CV barns. When examining the primiparous pens there were no differences between the housing systems.

Winter, spring, summer, and fall lameness prevalences were 17.0, 14.9, 9.5, and 9.8%, respectively. Winter and spring lameness prevalences were greater than summer and fall ($P < 0.001$). We observed during our winter visit that footbaths were not being used due to freezing conditions. Cook (2003) scored cows for lameness during the summer and winter and saw a similar pattern of higher lameness prevalence during the winter in the Midwest.

**Severe Lameness.** There were no differences among the housing systems for severe lameness prevalence. Severe lameness prevalences ($LS \geq 4$) were 1.6, 2.2, and 3.1% for CB, CV, and NV barns, respectively. Winter, spring, summer, and fall severe lameness prevalences were 4.3, 2.3, 1.0, and 1.6%, respectively. Peak severe lameness prevalence occurred between 30 and 150DIM.

### Hock lesion prevalence

Compost bedded pack barns had lower hock lesion prevalence (7.8%) than CV and NV barns (30.9%, $P = 0.003$ and 27.8%, $P = 0.012$, respectively; Table 4). The soft surface in CB barns is possibly more forgiving and reduces friction compared to sand bedded freestalls. In the current study, average pen prevalences ranged from 0 to 29.1%, 2.2 to 82.7%, and 0 to 83.3% in CB, CV, and NV barns, respectively. Hock lesion prevalence was greater during the spring and summer months. Although there was a seasonal relationship for hock lesion prevalence, this could be due to hair losses being typically covered by the longer hair during the colder months. Multiparous pens had more lesions than primiparous pens ($P < 0.001$).

***Severe Hock Lesions.*** Severe hock lesion prevalences ($HL = 3$) were 0.7, 7.4, 7.8% for CB, CV, and NV barns, respectively. There was an interaction between housing system and parity. Primiparous pens hock lesion prevalences were 0.2, 7.0, and 5.4% in CB, CV, and NV barns, respectively. In multiparous pens severe lesion prevalences were 1.3, 7.8, and 10.2% in CB, CV, and NV barns, respectively. The only difference was observed between primiparous and multiparous pens in NV barns ($P < 0.001$). Hock lesion prevalence was lower in the fall (4.1%) than spring and summer (6.9%, $P < 0.001$ and 6.8%, $P < 0.001$, respectively) and was not different in winter (3.7%). Winter was lower than spring and summer ($P < 0.001$). Spring and summer hock lesion prevalences were not different. Pens that were less than 30 DIM had a prevalence of 3.6%, pens between 30 and 150 DIM, 4.7%, and pens greater than 150 DIM, 7.7%. Pens less than 30 DIM and pens between 30 and 150 DIM were lower than pens greater than 150 DIM ($P < 0.001$) with no differences between less than 30 DIM and between 30 and 150 DIM.

**Hygiene**

Mean hygiene scores (scale of 1 to 5, where 1=clean, 5=dirty) were 3.18, 2.83, 2.77 for CB, CV, and NV barns, respectively. The CB barns had higher hygiene scores than CV and NV barns ($P = 0.024$ and $P = 0.01$, respectively). Seasonal hygiene scores were 2.94, 2.76, 3.03, and 2.97 for winter, spring, summer, and fall, respectively. Spring hygiene scores were lower than winter ($P = 0.003$), summer ($P < 0.001$), and fall ($P < 0.001$). There was a housing system by season interaction. The CB barns had higher hygiene scores during the winter than the CV and NV barns ($P = 0.007$ and $P = 0.029$, respectively). During the winter it was more difficult for the producers in CB barns to manage the pack and keep the surface dry. Hygiene scores in CV barns varied across seasons. Summer hygiene scores were significantly higher than winter and spring scores. There were no differences in hygiene scores among winter, spring, and fall measurements in the CV barns. Hygiene scores improved throughout lactation. Scores were 3.01, 2.95, and 2.82 for less than 30 DIM, between 30 and 150 DIM, and greater than 150 DIM, respectively. Pens less than 30 DIM and between 30 and 150 DIM had greater hygiene scores than pens greater than 150 DIM ($P = 0.004$ and $P = 0.018$), with no differences between the early lactation groups.

**Body condition**

There were no differences among housing systems for BCS (mean of 2.95). Seasonally, BCS scores were higher in the winter than summer and fall ($P < 0.001$) with no differences between spring and winter. Spring BCS were greater than summer ($P < 0.001$). Multiparous pens had greater BCS than primiparous pens ($P < 0.001$). Pens less than 30 DIM had lower BCS than pens greater than 150 DIM ($P < 0.001$). Pens between 30 and 150 DIM had a trend for lower BCS than pens less than 30 DIM and were lower than pens greater than 150 DIM ($P = 0.068$ and $P < 0.001$, respectively). Each additional kg of milk yield reduced BCS by 0.001 ($P < 0.001$).

**Cow comfort index**

Naturally ventilated barns had a lower CCI than CV barns (80.3 vs. 86.4; $P = 0.015$). Summer had lower CCI (79.9) than winter (84.1; $P = 0.039$), spring (84.8; $P = 0.006$), and fall (84.4; $P = 0.002$). There were no differences in CCI between winter, spring and fall. Pens between 30 and 150 DIM had lower CCI (78.4) than pens less than 30 DIM (84.7; $P = 0.009$) and greater than 150 DIM (86.9; $P < 0.001$). There were no differences for pens between 30 and 150 DIM and pens greater than 150 DIM. Nelson (1996) recommended that CCI be at least 80% and ideally greater than 85% as indication of good stall comfort. The CV barns and 3 of the seasonal averages were near the recommended percentage. The NV barns were 4.7 percentage units lower than the recommended 85%; however, the current results were higher than previously reported 76% with mattress stalls (Cook et al., 2005).

**Respiration rates**

In the current study we used the THI of 70 as the onset of heat stress. Mild to moderate heat stress was classified as THI between 70 and 78 and severe heat stress when THI was greater than 78. Twenty-seven percent of the respiration rate measurements were taken when the THI was less than 70, 66.5% when THI was between 70 and 78, and 6.4% when THI was greater than 78. Approximately 75% of the measurements were taken when there was some heat stress. Respiration rates were 59.5, 57.9, and 59.4 breaths/min in CB, CV, and NV barns, respectively, and they were not significantly different among systems. The variables that were offered to the respiration rate model were parity, milk production, somatic cell score, and outside THI. Only milk production and outside THI were significant ($P < 0.001$). Respiration rates based on the three outside THI categories were 51.2, 57.5, and 67.5 breaths/min when THI was less than 70, between 70 and 78, and greater than 78, respectively. Each additional kg of milk yield was associated with an increase in respiration rate of 0.13 ($P < 0.001$). Higher milk production increases a cow's susceptibility to heat stress. During hot weather dairy cows try to combat heat stress by reducing dry matter intake and eventually milk production decreases.

Cross-ventilated barns with evaporative cooling were built to improve summer time cooling to provide a more comfortable environment for animals and employees. The CV barns had a 2.0 and 2.1 unit lower THI compared to CB ($P = 0.023$) and NV ($P = 0.018$) barns, respectively during the summer (from June 21 to September 22). However, respiration rates were only numerically lower than CB and NV barns.

### Mastitis prevalence

Subclinical mastitis infection prevalence was used as an indirect measurement of welfare in this study. Subclinical mastitis infection prevalences (SCC > 200,000) were 33.4, 26.8, and 26.8% for CB, CV, and NV barns, respectively, with no differences in prevalence among housing systems.

### Culling and mortality

Herd turnover rates were 30.1, 24.6, and 29.0% in CB, CV, and NV barns, respectively. Mortality rates were 5.1, 5.8, and 5.0% in CB, CV, and NV barns, respectively. One CV and 1 NV barn were excluded from analysis due to substandard on-farm records. There were no differences among the housing systems for herd turnover or mortality rates.

Herd turnover rate for animals that left the herd less than 60 DIM were 6.0, 5.6, and 9.4% in CB, CV, and NV barns, respectively. There was a trend for NV barns to have greater herd turnover than CV ($P < 0.084$) and CB ($P = 0.092$) barns with no differences between CB and CV. Mortality rates for animals that left the herd less than 60 DIM were 2.3, 2.5, and 2.8% in CB, CV, and NV, respectively.

Overall the top 3 reasons for animals to be sold in the current study were sick or injured (24.4%), breeding (20.7%), and mastitis (16.5%). The top reasons for being sold in CB barns were breeding (24.0%), mastitis (20.2%), and sick or injured (19.3%). The top reasons for being sold in CV barns included sick or injured (20.9%), breeding (18.4%), and production (16.6%). For

CV barns, 15.8% of the sold observations did not contain a remark which could influence the percentages in each category compared to 3.1 and 3.8% of non reported reasons in CB and NV barns, respectively. The top reasons in NV barns were sick or injured (34.0%), breeding (19.1%), and mastitis (16.8%). When comparing the percentages of reasons for leaving the farm there were no differences among housing systems for mastitis, production, breeding, dairy, sick or injured, or miscellaneous.

When animals were sold from the herd within the first 60 DIM, the primary reason was sick or injury (42.8%). The next two causes were mastitis (19.3%) and miscellaneous (15.9%) reasons which included udder conformation. Being sick or injured was the most common reported reason for leaving the herd, being 40.5, 32.9, and 55.4% in CB, CV and NV barns, respectively. After sickness or injury, the next most common reported reason for leaving the herd was mastitis in CB barns (25.8%), or miscellaneous reasons in CV (23.6%) and NV (24.4%) barns, respectively. The CV barns had 13.6% of the reasons not reported, which could change the interpretation if the reasons had been reported. Of the sick or injured category, 31.4% resulted from sick animals that most likely had transition problems after calving. Lameness issues accounted for 23.7% from the sick or injured category.

## Conclusions

Low profile CV barns had statistically higher aerial ammonia and hydrogen sulfide concentrations than NV and CB barns; however, these differences were not biologically significant and were not expected to have adverse effects on the cows or workers. The CV barns in our study were near the minimum for recommended light intensity. Producers should consider additional lighting and better light fixture maintenance to provide adequate lighting for workers and animals. CV barns with evaporative cooling pads were 2 to 3 °C cooler than NV and CB barns when the outside temperature was greater than 27°C. Bacterial counts from the bedding and milk bulk tank samples were similar for CB, CV, and NV barns.

Of the three dairy cattle housing options examined in this study, CB barns appeared to provide the most welfare friendly facility. Dairy cattle housed in CB barns had reduced lameness and hock lesions compared to CV and NV barns with no adverse associations with body condition, heat stress, mastitis infection prevalence, culling, or mortality. When comparing the two freestall housing options, CV barns had improved cow comfort index compared to NV barns. Respiration rates were numerically lower in CV barns during the summer than CB and NV barns; however, there was no significant difference. Although CB barns appeared to provide an improved welfare environment, ability of acquiring bedding and managing the bedding pack can limit their use.

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