Environmental Characteristics and Bacterial Counts in Bedding and Milk Bulk Tank of Low Profile Cross-Ventilated, Naturally Ventilated, and Compost Bedded Pack Dairy Barns

K. M. Lobeck, M. I. Endres, K. A. Janni, S. M. Godden, J. Fetrow

Abstract. *Low profile cross-ventilated freestall (CV) and compost bedded pack barns (CB) are two newer housing options for dairy producers in the Upper Midwest. The CV barns are fully enclosed facilities that rely on mechanical ventilation and typically use evaporative cooling for heat abatement during the warmer months. The CB barns are a loose housing system that is generally bedded with dry wood sawdust and tilled twice daily. The objectives of this study were to describe the housing system and assess air quality (aerial ammonia and hydrogen sulfide), air velocity, light intensity, temperature, and relative humidity in CV, CB, and naturally ventilated freestall barns (NV). This cohort study was conducted on 18 commercial dairy farms, 6 of each housing type, in Minnesota and eastern South Dakota. Farms were visited four times, once each season between January and November 2008. Ammonia, hydrogen sulfide, light intensity, and air velocity measurements were taken twice each visit with 10 measurements per sampling time. Aerial ammonia concentrations were significantly higher in CV barns than CB and NV barns (5.2, 3.9, and 3.3 ppm, respectively). Hydrogen sulfide concentrations were 18, 33, and 19 ppb in CB, CV, and NV barns, respectively. There was a trend for higher hydrogen sulfide concentrations in CV barns. Light intensity was significantly lower in CV barns than CB and NV barns (111, 480, and 392 lux, respectively). There were no differences in air velocity among the housing systems. The mechanically ventilated CV barns were warmer in the fall and winter than the CB and NV barns. When outside temperature was above 27°C, CV barns were 2.9°C and 3.0°C cooler than CB and NV barns, respectively. No differences were seen in bedding or bulk tank bacterial counts among the housing systems. Although CV barns had significantly higher aerial ammonia and a trend for higher hydrogen sulfide concentrations than NV and CB barns, ammonia and hydrogen sulfide concentrations were below the threshold that would affect cow performance or human health. In conclusion, the three housing systems assessed had adequate air quality and ventilation to provide a safe environment for workers and animals.*

Keywords. *Cross-ventilated, Compost barn, Ammonia, Hydrogen sulfide, Light intensity, Air velocity.*

Cross-ventilated (CV) freestall barns and compost bedded pack (CB) barns are newer dairy housing options used in the Upper Midwest. The first CV barn was built in North Dakota in December 2005. These barns have a low roof pitch of 0.5/12 which is different than conventional naturally ventilated (NV) freestall barns typically with a roof pitch of 3/12 or 4/12 (Smith and Harner, 2007). They are built like conventional single story warehouse structures and are fully enclosed with air being pulled through the facility perpendicular to the ridge with fans (Smith and Harner, 2007; Smith et al., 2008). Air enters the barn through evaporative cooling pads that line one lengthwise side of the barn and is exhausted through the opposite wall which is lined with fans (Sheffield et al., 2007). Internally CV barns are laid out similar to multiple 4-row or 6-row barns side by side and can have up to 20 rows and be over 150 m wide (Sheffield et al., 2007; Jacobson et al., 2008).

Cross-ventilated barns have baffles placed over the freestall areas in the pen to encourage cows to lie down in warm weather (Harner et al., 2007). Baffles are typically made of metal, but can also be made of a canvas material. Baffles in CV barns are placed 1.8 to 3.0 m above the floor to increase air velocity past the cows, whereas baffles in tunnel ventilated barns need to be placed 3.7 to 4.0 m above the floor to allow machinery passage (Sheffield et al., 2007). Baffles can increase the air speed in the stall area from 0.9-1.3 to 2.7-3.6 m/s (Smith et al., 2008) which increases the air velocity over the cows and heat loss from the cows to minimize heat stress.

Evaporative cooling (removing energy from the air by evaporating water, lowering air temperature, and increasing air humidity) has been used successfully in tunnel ventilated barns and other applications (Bucklin et al., 1991). It has been able to reduce barn air temperatures in arid climates, being less effective as ambient humidity increases (Brouk et al.,

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2003). The most common form of evaporative cooling in CV barns uses cooling pads, pumps to circulate the water through the pads, and the cooled air is pulled through the barn by a pressure drop created by fans on the opposite wall (Jacobson et al., 2008). Evaporative cooling has helped maintain cooler barn temperatures in regions of the upper Midwest that typically have high heat and drier climates.

Studies conducted in tunnel barns with evaporative cooling during the summer months have shown reduced respiration rates, lower rectal temperatures, improved pregnancy rates, reduced days open, and increased milk production compared to other heat abatement strategies (Wise et al., 1988; Ryan et al., 1992; Smith et al., 2006). However, in humid climates the evaporative cooling is less effective and can cause the barn temperature-humidity index to be greater than ambient (Brouk et al., 2001).

Low profile CV barns with evaporative cooling are expected to improve summertime cooling and improve temperature control in the winter to allow the barn to be warmer than outside ambient temperatures (Jacobson et al., 2008). Other advantages of CV dairy barns (in comparison to conventional NV freestall barns) include smaller building footprint, shorter walking distances to and from the parlor, and controlled lighting (Smith et al., 2008).

The other new housing option in the upper Midwest is a bedded pack system most commonly known as compost bedded pack barn (CB). The first CB barn was built in Minnesota in 2001. Characteristics of these barns include a resting pack area that is typically bedded with dry wood sawdust. Mixing fans are used over the resting pack and the feed bunk to promote heat abatement. Mixing fans over the pack also dry the top layer of the pack. 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. Bedding can accumulate in the pack up to 1.2 m deep. Unlike conventional bedded packs, compost packs are tilled twice daily to incorporate the manure and provide a fresh, dry surface when cows return from the parlor. Various types of equipment can be used for tilling, including cultivator, rotary tiller, and chisel plow, and the depth of tilling is usually approximately 25 cm. For more details on compost barn design and management see Barberg et al. (2007) and Janni et al. (2007). Key reasons cited by producers to build these facilities were improved cow comfort and cow longevity (Barberg et al., 2007).

There has been limited research evaluating CV and CB housing systems. Therefore, the objectives of this observational study were to describe the housing systems and assess ammonia and hydrogen sulfide concentrations, air velocity, light intensity, temperature, humidity, bacterial counts in bedding material and milk bulk tanks in CV, CB, and conventional NV barns. Naturally ventilated freestall barns were included in the study because they are the most common housing system for larger dairies in the Upper Midwest.

Materials and Methods

Farms

This cohort study was conducted on 18 dairy operations in Minnesota and South Dakota. Only barns occupied for at least one year prior to the start of the study were included. This requirement limited the number of herds to six used in each housing type to match the number of herds in each system. Few CV herds were available and willing to participate in the study when the study was initiated. All of the CV and NV dairies had sand bedded freestalls and all but one used recycled sand for bedding.

Dairy farms were visited four times, once each season between January and November 2008. Data collection occurred during January and February (winter), April and May (spring), July and August (summer), and October and November (fall). Data collection included: building dimensions and layout, temperature-humidity index inside the barn and outside (nearest weather station), aerial ammonia and hydrogen sulfide concentrations, air velocity, light intensity, bedding cultures, and milk bulk tank cultures.

Environmental Measurements

Aerial ammonia and hydrogen sulfide concentrations, air velocity, and light intensity were measured twice daily during each visit. Ten measurements were taken each sampling time – five along the feed bunk and five inside a pen in the CB and NV barns. In NV barns the high production group was the selected bunk and pen for measurements. In CB barns, measurements were recorded throughout the entire length of the barn due to their smaller size. In the CV barns, two sets of measurements were taken: one in a pen closest to the inlet or cooling pads and another in a pen near the exhaust or fan side of the barn (for a total of 20 measurements at each sampling time). Ammonia concentration was measured using a Dräger Pac III meter (Accuracy < 3 ppm, response time ≤ 20 s; Dräger Safety Inc., Pittsburg, Pa.). Hydrogen sulfide concentration was measured with a Jerome 631-X meter (Accuracy ±3 ppb; Jerome Hydrogen Sulfide Analyzer; Arizona Instrument LLC, Tempe, Ariz.). Air velocity was measured using an anemometer (Accuracy ±0.05 m/s, response time 0.4 s; TSI VELOCICHEC® Air Velocity meter, Model 8330; TSI, Inc., Shoreview, Minn.). Light intensity was measured (during the day or when lights were turned on) using a digital light meter (Accuracy ±25 lux, response time 12 s; model TES1337; TES Electrical Electronic Corp., Taiwan, ROC). All measurements were taken approximately 1 m from the floor and after a 1-min wait for equipment to stabilize.

The temperature and humidity inside the barn were recorded an entire year (January 2008 – January 2009) at hourly intervals using a data logger (Temperature accuracy ±0.5°C, RH accuracy ±3%; Hobo® H8 Pro Series, Bourne, Mass.). One data logger was placed in the CB and NV barns. Two data loggers were placed in the CV barns, one at the first baffle on inlet side and one at the last baffle on the outlet side over the freestalls. Average temperature and relative humidity values using both data loggers were used for the CV analysis. Hourly outdoor temperature and humidity were obtained from the nearest weather station to each barn (http://climate.sdstate.edu/airport/surface/archive.asp). The equation used to calculate the temperature-humidity index (THI) was: $THI = td - (0.55 - 0.55RH)(td - 58)$ where td was the dry bulb temperature in °F and RH is relative humidity expressed as a decimal (West et al., 2003). Mean temperatures and relative humidity from barn and ambient values were used to calculate humidity ratios using equations in the Psychrometrics chapter (Chapter 1) of the 2009

ASHRAE Handbook – Fundamentals (ASHRAE, 2009). Seasons were grouped based on the calendar year, starting in January when data loggers were installed and ending 20 December 2008.

Bedding Bacterial Analysis

For the CV and NV barns the high production pen was selected. Surface samples from a minimum of 20 stalls randomly selected along the length of the pen were collected. For the CB barns, four main areas of the bedding pack were used with a minimum of five surface samples taken and composited within each of the four main areas. Samples were thoroughly mixed and immediately cooled upon collection and later frozen at -40°C. Frozen samples were taken to the Laboratory for Udder Health at the University of Minnesota for analysis and thawed inside a refrigerator. Fifty cubic centimeters of bedding material were measured using a sterile container and placed into a Whirl-Pak® bag (Nasco, Fort Atkinson, Wis.). Two hundred fifty cubic centimeters (cc) of sterile distilled water were added to the bedding material which was mixed and allowed to stand for 10 min. The sample was mixed again, a liquid sample was removed by pipette and serial 10-fold dilutions were made in sterile Brain Heart Infusion broth. Sample dilutions were plated (200 μL) on colistin naladixic acid (CNA) agar (BBL, Sparks, Md.), MacConkey agar (BBL, Sparks, Md.), and thallium sulfate-crystal violet-B toxin blood (TKT) agar medium. Colony counts were determined for each sample after 24 h of incubation at 37°C. Bacterial groups were identified as coliforms (lactose-positive colonies on MacConkey's agar, which include *Klebsiella* by visual identification), *Streptococcus* species (growth on TKT agar), *Bacillus* species (growth on CNA agar and gram-positive), and coagulase negative staphylococci (growth on the CNA agar and catalase activity). Bacteria counts were expressed as colony forming units (cfu)/mL of bedding sample.

Milk Bacterial Analysis

Milk bulk tank samples were collected during winter and summer from five consecutive bulk tank pickups by the milk plant personnel at each dairy. Samples were immediately frozen after collection and shipped in a cooler to the Laboratory for Udder Health, University of Minnesota and used for bacterial culture. For analysis, samples were thawed inside a refrigerator. Once thawed, samples were thoroughly mixed, and 2-mL were removed from each sample and pooled into a sterile tube. After mixing, serial 10-fold dilutions were made in sterile brain heart infusion broth. Two hundred microliters from each dilution were spread over the surface of separate MacConkey agar, TKT agar, and Factor agar plates. After 24 h of incubation at 37°C, the plates having 30 to 300 colonies were chosen for enumeration of bacteria. Those colonies that appeared to be *Staphylococcus aureus* were presumptively identified by catalase activity, tube coagulase test, and biochemical reactions using the API-STAPH (BioMerieux, Hazelwood, Mo.). Bacterial counts were recorded as number of bacteria per mL of bulk tank milk.

Statistical Analysis

Comparative analysis between housing systems and season were performed using PROC MIXED of SAS (SAS Inst. Inc., Cary, N.C.). Housing type was used as the explanatory variable in all models. Additional explanatory variables included in models were season of the year, air velocity in relation to hydrogen sulfide and ammonia concentrations, area of the pen (feed bunk or stall/pack area), and area of the barn (inlet or exhaust side only for CV barns). Interactions examined were system by season and area of pen by system. Dependent variables were ammonia concentration (ppm), hydrogen sulfide concentration (ppb), light intensity (lux), air velocity (m/s), housing system temperature (°C), bedding bacterial counts (cfu/mL), and milk bulk tank bacterial counts (cfu/mL). Repeated measure analysis was used for hydrogen sulfide, ammonia, air velocity, and lighting measurements. Farm was the random effect for temperatures, THI, temperature differences from ambient, humidity differences from ambient, and bulk tank and bedding bacterial counts. Those variables identified in the univariate screening test ($P < 0.3$) were used to build the mixed model. Backwards stepwise elimination was used until remaining variables included were significant ($P < 0.05$). Multiple means comparisons were carried out using the Tukey-Kramer methodology (Zar, 2009). After examining residual plots, hydrogen sulfide concentration, light intensity, and bacterial counts for milk and bedding were not normally distributed and were natural log transformed for analysis. The results were back transformed to geometric means and 95% confidence intervals for interpretation. The relationships between barn temperatures and nearest weather station temperatures were analyzed using PROC CORR of SAS. Comparisons of intake and exhaust temperatures of CV barns were compared using the paired option of PROC TTEST of SAS.

Results and Discussion

Barn Characteristics

Figures 1, 2, and 3 are representative diagrams of the NV, CV, and CB barns that participated in the study. All CV and NV barns had deep bedded sand freestalls. Stall dimensions were similar between CV and NV barns. Average stall lengths were (cm; means ± SD) 239.3± 11.4; stall widths were 117.7 ± 4.9; neck rail heights were 115.34± 7.5; and body resting lengths were 166.8 ± 9.2. The CB barns used mainly wood sawdust as a bedding source with the exception of one barn using a wheat straw by-product. All CV barns and three NV barns used manually driven equipment to scrape manure from the alleys into a flush flume. Two NV barns used a flush system to remove manure from alleys into a flush flume. One NV barn used manually driven equipment to scrape manure from the alleys into a storage basin. All CV and five of the six NV barns reclaimed sand bedding with a sand settling lane. All six CB barns scraped manure from the

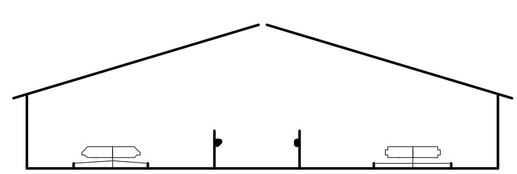

Figure 1. End view of a 4-row naturally ventilated freestall dairy barn.

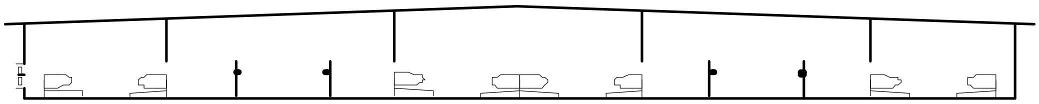

Figure 2. End view of an 8-row cross-ventilated freestall dairy barn

Figure 3. End view of a naturally ventilated compost dairy barn.

feed alley into a short-term storage basin with manually driven equipment.

Table 1 shows barn characteristics including barn dimensions, number of pens, cows per pen, stocking density, and linear water space. Description of lighting and fans are shown in tables 2, 3, and 4.

Tables 2, 3, and 4 describe the ventilation and lighting by farm within each of the housing systems (i.e. CB, CV, NV).

Environmental Characteristics

Aerial Ammonia Concentrations

Ammonia concentrations (ppm, LS Mean ± SE) were 3.9 ± 0.35 for CB, 5.2 ± 0.35 for CV, and 3.3 ± 0.35 for NV barns (table 5). The CV barns had greater concentrations than CB and NV barns ($P = 0.049$ and $P = 0.005$, respectively), whereas CB and NV barns were similar. Summer had the highest concentration of ammonia in all three housing systems ($P < 0.001$). This was expected, since ammonia in the gas phase is favored in warmer temperatures (Marcillac et al., 2007). Concentrations during winter, spring, summer, and fall were 3.5 ± 0.22, 4.0 ± 0.22, 5.6 ± 0.20, and 3.5 ± 0.25, respectively. Spring ammonia concentrations were greater than fall and winter ($P = 0.007$ and $P = 0.015$, respectively), whereas winter concentrations were similar to fall. Zhu et al. (2000) reported that ammonia concentrations measured in the fall were approximately 1 ppm in a naturally ventilated barn. Schmidt et al. (2002) had similar results in a NV freestall barn with 1.1 and 0.24 ppm during the summer and winter, respectively. Both of these studies only measured one dairy each and the size of the dairy was smaller than the farms included in this study. Sheffield et al. (2007) reported ammonia concentrations from 1.1 to 1.4 ppm during the spring and 1.1 to 1.2 ppm during the summer in a CV barn.

A separate analysis was performed to determine if there were differences in ammonia concentrations from the inlet to the exhaust side in CV barns. Ammonia concentrations were lower in the inlet side than the exhaust side of the barn (4.0 ± 0.27 vs. 6.2 ± 0.27, respectively; $P < 0.001$). Even though an increase in ammonia concentration was observed, this

Table 1. Barn characteristics of 18 barns (six each compost bedded pack, low profile cross-ventilated and naturally ventilated barns) in Minnesota and eastern South Dakota.

Barn	Barn Dimensions (m)	Sidewall Height (m)	Feed Alley Width[a] (m)	No. of Pens	Pack or Pen Dimensions (m)	No. of Stalls	No. of Cows in the Pen	Pack Area/Cow (m^2/cow)	Linear Water Space/Cow (cm)
Compost									
A	22 × 78	4.9	4.3	1	14 × 78	n/a	190	5.8	5.2
B	15 × 61	4.9	4.3	1	11 × 61	n/a	130	5.2	5.9
C	23 × 46	4.9	3.7	1	15 × 46	n/a	100	6.9	9.0
D	23 × 61	4.9	4.4	1	18 × 49	n/a	110	8.0	3.5
E	19 × 50	5.0	3.4	1	11 × 50	n/a	75	7.3	6.4
F[b]	30 × 95	4.9	3.4	4	8 × 46	n/a	50	7.4	7.3
Cross-ventilated								No. Cows/Stall	
A	90 × 198	4.1	3.1	10	14 × 92	204	240	1.2	6.1
B	69 × 101	4.7	3.7	4	11 × 82	122	125	1.0	4.5
C	90 × 198	4.1	3.1	10	14 × 92	204	240	1.2	6.4
D	64 × 95	4.0	3.7	8	12 × 41	63	85	1.3	5.0
E	65 × 73	4.3	4.0	4	13 × 67	99	110	1.1	4.3
F	98 × 184	4.3	4.0	12	11 × 88	130	150	1.2	7.3
Naturally ventilated									
A	34 × 101	4.0	3.8	6	14 × 94	230	320	1.4	4.9
B	30 × 213	4.3	3.1	10	12 × 104	152	185	1.2	4.3
C	29 × 235	4.4	4.0	4	11 × 134	192	205	1.1	7.1
D	29 × 173	4.0	3.4	7	11 × 83	132	145	1.1	2.3
E	27 × 95	3.7	3.7	9	11 × 44	72	88	1.2	4.6
F	33 × 105	3.7	3.8	6	14 × 51	113	125	1.1	6.4

[a] Feed alley is the front alley of the pen where the cows stand for eating from the feed manger.
[b] This barn had four pens of equal size.

Table 2. Description of mixing fans and lights in six compost dairy barns in Minnesota.

Barn	Fan Description[a]	Lighting Description
A	Four 7.3-m diameter low-speed high-volume fans, blowing downward, mounted horizontally, spaced uniformly over the pack; five 1.4-m diameter fans mounted vertically over the headlocks, tilted downward towards the feed alley placed uniformly along barn length.	Twenty-four fluorescent lights over pack; twelve fluorescent lights over feed alley. All spaced uniformly along barn length.
B	Three 7.3-m diameter low-speed high-volume fans, blowing downward mounted horizontally uniformly over the pack.	Seven low bay halogen lights over pack; eight low bay halogen lights over feed alley. All spaced uniformly along barn length.
C	Ten 1.3-m diameter fans mounted vertically above the headlocks blowing downwards toward the feed alley placed uniformly along barn length.	Twelve lights located over pack; six lights located over feed alley. All spaced uniformly along barn length.
D	Eleven 1.4-m diameter fans mounted vertically over the wall between the feed alley and pack, blowing downward towards the pack, spaced uniformly along barn length.	Twenty-five fluorescent lights over pack; nine fluorescent lights down feed manger. All spaced uniformly along barn length.
E	Seven 1.3-m ceiling fans mounted horizontally and spaced uniformly over the pack.	Four fluorescent lights spaced uniformly over the feed alley along barn length.
F	Six 1.2-m diameter fans mounted vertically above the pack, blowing downwards towards the pack; three 1.2-m diameter fans, mounted above the neck rail, blowing towards the feed alley, spaced uniformly along barn length	Two halogen lights over pack; six halogen lights down feed manger. All spaced uniformly along barn length.

[a] Feed alley is the front alley of the pen where the cows stand for eating from the feed manger.

should be of no biological consequence. According to the National Institute for Occupation Safety and Health (NIOSH) ammonia exposure should not exceed 25 ppm in a 40-h week (up to a 10-h day; Mitloehner and Calvo, 2008). None of the farms in the current 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 (ppb, LS Mean,95% CI) were 13, 9-19 for CB; 32, 22-45 for CV; and 17, 12-24 for NV barns (table 6). CV barns had higher concentrations than CB and NV barns (P < 0.006 and P = 0.044, respectively), whereas CB and NV barns were similar. 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). Hydrogen sulfide concentrations were 0 and 2 ppb for the winter and summer, respectively in a naturally ventilated freestall barn (Schmidt et al., 2002). Zhu et al. (2000) had similar results to the current study for hydrogen sulfide concentrations. They ranged from 4 to 26 ppb for the fall sampling in a NV freestall barn. Spring hydrogen sulfide concentrations in a CV freestall barn ranged from 7 to 14 ppb (Harner et al., 2007).

Hydrogen sulfide concentrations (ppb, LS Mean, 95% CI) on the inlet side within CV barns were lower than the exhaust side of the barn (19, 11-34 vs. 41, 24-71; P < 0.001). As the air moved through the barn, it was picking up the hydrogen sulfide that was being released from the degradation of the manure.

The recommended exposure limit for hydrogen sulfide by the NIOSH is 10 ppm for a 10-h work day in a 40-h work week (Mitloehner and Calvo, 2008). 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).

Table 3. Description of exhaust fans and lights in six low profile cross-ventilated dairy barns in Minnesota and South Dakota.

Barn	Fan Description[a]	Lighting Description
A	Seventy-eight 1.4-m diameter fans located on east side of barn.	Thirteen fluorescent lights per pen; seven over feed alley, six over back stall area. One hundred thirty five total lights.
B	Forty 1.4-m diameter fans located on north side of barn.	Twenty-two Orion fluorescent in pens 2, 3, and 4; twenty-seven in first pen. Ninety-three total lights.
C	Eighty-one 1.2-m diameter fans located on north side of barn.	Thirteen fluorescent lights per pen.
D	Thirty-six 1.3-m diameter fans located east side of barn.	Eight fluorescent lights per pen; five over feed bunk, three over back stall area. Sixty-four total lights.
E	Thirty-six 1.5-m diameter fans north side of barn.	Seven low bay halogen lights over driveway; seven lights over back stall area. Thirty-five total lights.
F	Ninety 1.3-m diameter fans and eleven 0.9-m diameter fans south side of barn.	Twelve fluorescent lights over feed bunk; one hundred-fifty total lights.

[a] Feed alley is the front alley of the pen where the cows stand for eating from the feed manger.

Table 4. Description of mixing fans and lights in six naturally ventilated freestall dairy barns in Minnesota and South Dakota.

Barn	Fan Description[a]	Lighting Description
A	Fourteen 1.2-m fans mounted vertically, blowing downwards, placed over the middle bank of stalls, spaced uniformly along barn length.	Seven metal halide lamps spaced uniformly along the length of the feed manger; fourteen lamps spaced uniformly along barn length.
B	Nine 1.2-m fans per pen mounted vertically, blowing downwards, placed over middle stalls, spaced uniformly along pen length.	Three fluorescent lights per pen over feed alley; twelve total spaced uniformly along barn length.
C	Ten 1.3-m fans per large pens and seven fans per small pens mounted vertically blowing downwards, placed over the middle bank of stalls spaced uniformly along pen length.	Thirteen fluorescent lights in two pens; seven lights in two smaller pens. Three lights spaced uniformly along barn length in the feed manger.
D	Seven 0.9-m fans over outer stalls; seven 0.9m fans spaced uniformly over middle stalls; nine 1.3m fans spaced uniformly over feed bunk.	Four metal halide lamp per pen over middle bank of stalls; three lights located over the feed bunk and vice versa for adjacent pen; four lights above alley to the parlor. Thirty-two lights total.
E	Forty-six 1.2- and 0.9-m fans spaced uniformly along barn length. Four fans each are mounted vertically above the middle and back bank of stalls blowing downward; three or four fans are mounted vertically over the headlocks blowing downward over the feed alley.	Seven low bay halogen lights spaced uniformly along length of driveway; Seven lights spaced uniformly along back stall area. Thirty-five lights total.
F	Fifty-six 0.9-m fans mounted vertically, blowing downward over both stalls and feed alley, spaced uniformly along barn length.	Seventeen halogen lamps spaced uniformly along the length of the feed bunk; twelve lights spaced uniformly along the length of back stall area.

[a] Feed alley is the front alley of the pen where the cows stand for eating from the feed manger.

Table 5. Ammonia concentrations (ppm) in compost bedded pack (CB), low profile cross-ventilated freestall (CV) and naturally ventilated freestall (NV) barns in Minnesota and eastern South Dakota.

	Housing System[a]							
	CB		CV		NV		Overall	
Season	LSMean	SE	LSMean	SE	LSMean	SE	LSMean	SE
Winter	3.5[b,x,y]	0.39	5.3[b,x]	0.37	1.7[c,y]	0.38	3.5[c]	0.22
Spring	3.8[b,x,y]	0.38	5.0[b,x]	0.36	3.1[b,y]	0.39	4.0[b]	0.22
Summer	4.9[a]	0.38	6.2[a]	0.36	5.8[a]	0.38	5.6[a]	0.22
Fall	3.4[b]	0.38	4.3[c]	0.36	2.8[b]	0.38	3.5[c]	0.22
Overall	3.9[y]	0.35	5.2[x]	0.35	3.3.[y]	0.35	4.2	0.27

[a] a,b,c Significant differences among rows ($P < 0.05$).
x,y Significant differences among columns ($P < 0.05$).

Table 6. Hydrogen sulfide concentrations (ppb) in compost bedded pack (CB), low profile cross-ventilated freestall (CV) and naturally ventilated freestall (NV) barns in Minnesota and eastern South Dakota.

	Housing System[a]							
	CB		CV		NV		Overall	
Season	LSMean	95% CI	LSMean	95% CI	LSMean	95% CI	LSMean	95% CI
Winter	31[a,y]	21-45	75[a,x]	53-108	31[a,y]	21-44	41[a]	34-51
Spring	12[b]	8-17	21[a]	15-30	13[b]	9-18	15[c]	12-18
Summer	10[b,y]	7-15	26[b,x]	18-37	22[a,x,y]	15-32	18[b]	15-22
Fall	9[b,y]	6-13	24[b,x]	17-34	9[b,y]	7-14	12[c]	10-15
Overall	13[y]	9-19	32[x]	22-45	17[y]	12-24	18	14-24

[a] a,b,c Significant differences among rows ($P < 0.05$).
x,y Significant differences among columns ($P < 0.05$).

The ASABE Standard EP344.3 (2005) recommends 70 lux or 6.5 foot candles (fc) for worker safety. Light intensity results were (lux, Geometric mean, 95% CI) 929, 562-1540 for CB barns; 118, 72-193 for CV barns; and 430, 260-712 for NV barns, respectively (table 7). The CV barns had lower light intensity than CB and NV barns ($P < 0.001$ and $P = 0.004$, respectively), whereas CB and NV barns were similar. The CV barns did not have the seasonal differences that the CB and NV barns experienced. Both CB and NV barns had the greatest light intensity during the summer and winter. Spring and fall did not differ in light intensity for CB barns, whereas they were lowest in the fall for NV barns. 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. 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 ($P = 0.005$, $P < 0.001$, $P = 0.04$,

Table 7. Light intensity (lux) in compost bedded pack (CB), low profile cross-ventilated freestall (CV), and naturally ventilated freestall (NV) barns in Minnesota and eastern South Dakota.

	Housing System[a]							
	CB		CV		NV		Overall	
Season	LSMean	95% CI	LSMean	95% CI	LSMean	95% CI	LSMean	95% CI
Winter[b]	881[a,b,x]	442-1758	120[y]	67-217	583[a,b,x]	292-1163	395[a,b]	270-578
Spring	769[b,x]	468-1262	130[y]	81-210	404[b,x,y]	244-670	343[b]	258-456
Summer	1318[a,x]	803-2162	119[y]	74-192	675[a,x]	411-1108	474[a]	361-621
Fall	836[a,b,x]	509-1371	104[y]	64-167	215[c,y]	131-353	265[c]	200-352
Overall	929[x]	562-1538	118[y]	72-193	430[x]	259-712	351	211-584

[a] a,b,c Significant differences among rows (*P* < 0.05).
x,y Significant differences among columns (*P* < 0.05).
[b] Includes only one set of measurements for each housing type due to meter malfunction

respectively). Summer light intensity was greater than spring (P < 0.001).

Light intensity measurements within the CV barns, area of the barn (inlet vs. exhaust), and area of the pen (feed bunk vs. stall area) were examined. The inlet side had greater light intensity than the exhaust side of the barn (lux, geometric mean, 95% CI; 137, 92-203 vs. 102, 69-152, respectively; P = 0.002). Average feedbunk measurements were greater than the stall measurements (127, 86-188 vs. 110, 74-164; P = 0.042). In the stall area the baffles block most of the light that normally would be distributed by the feed bunk lights.

In each of the housing systems during the four measured seasons there were instances when there was inadequate light intensity. 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 ± SE) 0.77 ± 0.09 for CB, 0.91 ± 0.09 for CV, and 0.66 ± 0.09 for NV barns, respectively (table 8). 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 tended to be greater than NV barns during the spring (P =0.028 and P = 0.056, respectively) with no differences between CB and NV barns. During the summer, there was a trend for CV barns to have greater air velocity than CB barns (P = 0.052). There were no differences between NV and CB, and CV and NV barns for air velocity during the summer. Air velocities differed each season (spring vs. summer, P = 0.011; all other comparisons, 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).

There was an interaction between pen area and housing system for velocity measurements. There were no differences in air velocity between the feed bunk and stall area for CB and NV barns. The only difference seen in air velocity between the two measurement areas was in the CV barns. Air velocity (LSMean ± SE) was greater under the baffles than in the feed bunk area: 1.3 ± 0.1 vs. 0.6 ± 0.1 m/s; P < 0.001, respectively. There was no difference between the inlet and exhaust side of the CV barns. The CV barns overall were able to maintain adequate ventilation while the air traveled through the barn.

The results of this study were lower than Harner et al. (2007) who observed air velocities that ranged from 2.67 to 3.05 m/s in a CV barn during May and August. Discrepancy in results is most likely due to sampling differences. For the current study, air velocities were measured both under the baffle and in the feed manger where air velocity decreased due to the lack of baffles. Harner et al. (2007) only had air velocity measurements under the baffle. Stowell et al. (2001) saw similar ranges in air velocities in a NV freestall barn with velocity ranging from 0.45 to 0.73 m/s.

Indoor and Outside Air Temperature and Relative Humidity

Figure 4 shows average indoor daily temperatures in each type of barn. Table 9 describes the barn temperatures, relative humidity, and summer THI along with outside temperatures, relative humidity, and THI. The average distance from the farm to the nearest weather station was 35 ± 16 km (mean ± SD). There was a high correlation between inside barn

Table 8. Air velocity (m/s) in compost bedded pack (CB), low profile cross-ventilated (CV), and naturally ventilated freestall (NV) barns in Minnesota and eastern South Dakota.

	Housing System[a]							
	CB		CV		NV		Overall	
Season	LSMean	SE	LSMean	SE	LSMean	SE	LSMean	SE
Winter	0.50[b]	0.12	0.26[c]	0.10	0.29[c]	0.11	0.35[d]	0.06
Spring	0.79[b,y]	0.10	1.30[a,x]	0.09	0.80[a,b,y]	0.11	0.96[b]	0.06
Summer	0.93[a]	0.10	1.41[a]	0.09	1.01[a]	0.10	1.12[a]	0.06
Fall	0.88[a]	0.10	0.66[b]	0.09	0.55[b]	0.10	0.70[c]	0.06
Overall	0.77	0.09	0.91	0.09	0.66	0.09	0.82	0.06

[a] a,b,c,d Significant differences among rows (*P* < 0.05).
x,y Significant differences among columns (*P* < 0.05).

temperature and outside temperature in the CB and NV barns (0.81-0.97), 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, the correlation was lower in the winter (0.62) because the barn temperatures were higher than outside temperatures.

Cross-ventilated barns had indoor temperatures 14.0 ± 0.7°C warmer than outside in the winter and had a greater difference than CB and NV barns ($P < 0.001$). Temperatures in the CB and NV barns were 5.9 ± 0.6°C and 6.8 ± 0.6°C warmer than outside, respectively. During the spring, CB, CV, and NV barns were similar and barn temperatures were 1.7 ± 0.6°C, 2.9 ± 0.7°C, and 1.9 ± 0.03°C greater than outside, respectively. During the summer, CB and NV barns had indoor temperatures similar to outside whereas CV barns were 0.4 ± 0.7°C cooler than outside. However, there was no difference among the three housing systems. Fall barn temperatures averaged 2.8 ± 0.6°C, 7.0 ± 0.7°C, and 3.4 ± 0.6°C warmer in CB, CV, and NV barns, respectively, than outside temperatures. The CV barns maintained a greater temperature difference than both CB and NV barns ($P <0.001$ and $P = 0.003$, respectively). Barns were typically warmer than outside temperatures most likely due to insulation, closing up the barn, and heat produced by the cattle. With the evaporative cooling, the CV barns were able to drop the barn temperature during the summer.

One weather station that was used for one CB and one CV barn reported extremely low relative humidity levels either from a malfunctioning hygrometer or data entry errors. The incorrect relative humidity data were excluded from analysis. Correlations were strong between barn and weather station relative humidity for spring and fall for all of the housing systems. During the winter, the correlations were lower in the CV and NV barns (0.44 and 0.46, respectively). During summer, indoor and outside relative humidity in CV barns were less correlated (0.52) than the CB and NV barns; this is most likely caused by the use of evaporative cooling which added moisture inside the CV barns.

The differences between barn humidity ratios and outside humidity ratios (LSMean±SE; kg H_2O/kg dry air) were 0.0017 ± 0.0008, 0.0023 ± 0.0001, and 0.0018 ± 0.0001 in CB, CV, and NV barns, respectively. There were no differences among the three housing systems. There were seasonal differences ($P < 0.001$) in barn vs. outside humidity ratios with summer (0.0031 ± 0.0005) being greatest, followed by fall (0.0019 ± 0.0005), spring (0.0016 ± 0.0005), and winter (0.0011 ± 0.0005).

Barn and outside THI correlations were only used for 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.

Average barn temperatures were 8.4°C, 11.0°C, and 9.4°C in CB, CV, and NV barns, respectively (table 10). During the winter, CV barns were significantly warmer than CB and NV barns ($P < 0.001$). The CV barns were 5.3°C and 7.6°C warmer than CB and NV barns in the winter most likely due to a reduced number of fans running in the barn during that time and having a fully enclosed and insulated structure. During the fall, the CB and NV barns were also colder than the CV barns ($P < 0.001$). As expected, within housing system there were differences in seasonal temperatures.

We performed a warm weather analysis with all outdoor temperatures less than 27°C excluded from the dataset and found that CV barns were 3.6°C cooler than CB barns and 3.3°C cooler than NV barns ($P < 0.001$). There was no difference between NV and CB barns which was expected from their similar ventilation and heat abatement methods. Summer THI in CV barns was 2.1 and 2.5 units lower than CB and NV barns, respectively. When excluding outdoor temperatures less than 27°C, the THI in CV barns was 3.1 and

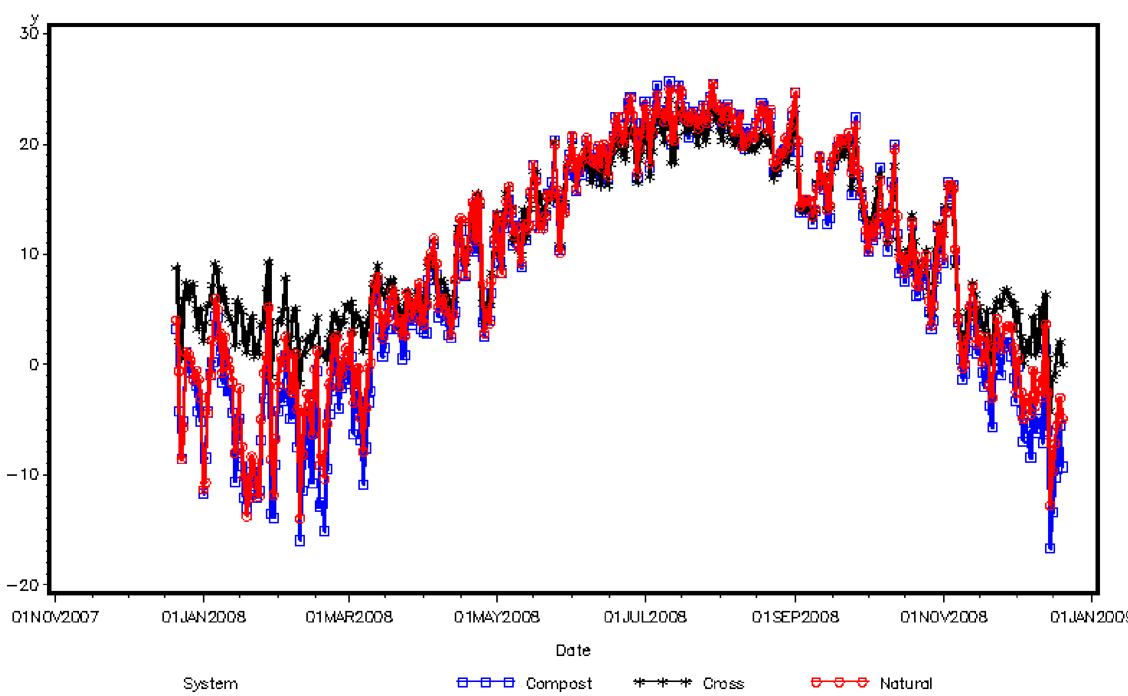

Figure 4. Average daily barn temperatures in compost bedded pack (CB), cross ventilated (CV), and naturally ventilated freestall barns in the upper Midwest.

Table 9. Barn temperatures, relative humidity (RH), temperature-humidity index (THI), and Pearson correlation coefficient (r) between barn and outside temperatures, relative humidity, and THI in compost bedded pack (CB), low profile cross-ventilated freestall (CV) and naturally ventilated freestall (NV) barns in Minnesota and eastern South Dakota.

Barn	Season	n	Barn Temp (°C)	Min	Max	n	Outside Temp (°C)	Min	Max	r
CB										
	Winter	7108	-3.8	-27.1	14.5	6433	-10.2	-40.6	12.2	0.81
	Spring	12751	11.8	-9.5	32.3	11873	10.0	-13.3	31.1	0.96
	Summer	13248	20.7	5.4	35.7	12242	20.1	1.1	32.8	0.96
	Fall	13108	5.0	-23.4	31.1	12800	2.1	-39.4	30.0	0.97
CV										
	Winter	3669	4.4	-5.9	15.8	4670	-9.5	-40.6	11.7	0.62
	Spring	13248	12.2	-5.3	30.1	12339	9.9	-13.3	30.6	0.90
	Summer	13392	19.6	5.0	30.9	12298	20.5	2.2	35.0	0.90
	Fall	12965	8.2	-9.1	25.2	12700	2.3	-39.4	31.1	0.84
NV										
	Winter	8439	-1.8	-24.3	16.8	8190	-8.5	-31.1	11.1	0.92
	Spring	13248	12.2	-6.8	30.7	12512	10.2	-13.3	30.0	0.97
	Summer	13248	20.8	3.3	32.8	12392	20.1	1.1	32.8	0.95
	Fall	13110	6.4	-22.6	28.7	12899	2.9	-30.6	30.0	0.97
Barn	**Season**	**n**	**Barn RH%**	**Min%**	**Max%**	**n**	**Outside RH%**	**Min%**	**Max%**	**r**
CB										
	Winter	7055	83.2	14.6	99.9	6269	60.2	3.0	100	-0.17
	Spring	12596	68.9	14.6	99.9	11594	56.5	3.0	100	0.57
	Summer	12009	72.2	23.5	99.8	11633	62.0	3.0	100	0.55
	Fall	11707	78.0	18.6	99.9	12801	62.5	3.0	100	0.43
CV										
	Winter	3652	81.0	44.2	99.7	4506	51.4	3.0	100	-0.17
	Spring	13048	69.3	13.5	99.7	12060	58.2	3.0	100	0.51
	Summer	11733	81.0	19.6	99.8	11682	62.9	3.0	100	0.29
	Fall	11446	76.9	22.3	99.8	12203	66.1	3.0	100	0.41
NV										
	Winter	7698	77.8	39.2	99.9	8098	72.7	3.0	100	0.44
	Spring	11234	66.8	18.2	99.9	12512	64.9	15.0	100	0.90
	Summer	9159	72.1	27.9	99.9	12392	68.7	22.0	100	0.88
	Fall	8919	74.7	26.6	99.9	12865	72.5	16.0	100	0.84
Barn	**Season**	**n**	**Barn THI**	**Min**	**Max**	**n**	**Outside THI**	**Min**	**Max**	**r**
CB	Summer	12009	67.7	42.0	83.3	10287	65.7	35.1	83.0	0.95
CV	Summer	11733	65.9	40.8	83.0	10319	66.4	37.0	83.9	0.93
NV	Summer	9159	68.2	42.6	85.3	12392	65.8	35.1	82.8	0.94

3.3 units lower than CB and NV barns, respectively ($P < 0.001$). All housing systems had THI greater than 72 which indicated that all cows were experiencing some heat stress (Armstrong, 1994).

A separate analysis within the CV barns was performed to determine whether there were temperature or humidity ratio (kg H_2O/kg dry air) differences between the inlet and exhaust sides of the barn. The exhaust side of the barn (mean difference ± SD) was 3.0 ± 1.7°C; 2.1 ± 2.1°C; 0.9 ± 1.1°C, and 3.4 ± 2.5°C warmer ($P < 0.001$) than the inlet side of the barn for winter, spring, summer, and fall, respectively. The exhaust side humidity ratios (mean difference ± SD) were 0.0007 ± 0.0005; 0.0007 ± 0.0006; 0.0007 ± 0.0009; and 0.0012 ± 0.0012 greater ($P < 0.001$) than the inlet side humidity ratios for winter, spring, summer, and fall, respectively. We expect that these differences in temperature and humidity ratios were not biologically significant and were not affecting animal performance.

Bedding Bacterial Counts

Geometric means of bacterial counts (cfu/mL) from bedding cultures are presented in table 11. Overall counts (geometric mean) were 6,000; 31; 4,000,000; 2,000; and 197,000 cfu/mL for coliforms, *Klebsiella*, 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

Table 10. Barn temperatures (Temp °C) and barn temperature-humidity index (THI) in compost bedded pack (CB), low profile cross-ventilated freestall (CV) and naturally ventilated freestall (NV) barns in Minnesota and eastern South Dakota.

		Housing System[a]							
		CB		CV		NV		Overall	
Temp (°C)	Season	LSMean	SE	LSMean	SE	LSMean	SE	LSMean	SE
	Winter	-3.7[d,y]	0.49	3.9[d,x]	0.50	-1.4[d,y]	0.49	-0.4[d]	0.28
	Spring	11.8[b]	0.49	12.2[b]	0.49	12.2[b]	0.49	12.1[b]	0.28
	Summer	20.7[a]	0.49	19.6[a]	0.49	20.8[a]	0.49	20.8[a]	0.28
	Fall	5.0[c,y]	0.49	8.2[c,x]	0.49	6.4[b,x,y]	0.49	6.5[c]	0.28
	Overall	8.4[x]	0.48	11.0[y]	0.48	9.4[xy]	0.48	11.2	0.49
THI									
	Summer[b]	68.0[x]	0.44	65.9[y]	0.44	68.4[x]	0.44	67.3	0.36
	≥ 27°C[c]	76.2[x]	0.47	73.1[y]	0.47	76.4[x]	0.47	75.2	0.43

[a] a,b,c,d Significant differences among rows ($P < 0.05$).
x,y Significant differences among columns ($P < 0.05$).
[b] Barn THI during the summer season (21 June – 22 September 2008).
[c] THI after outside ambient temperatures less than 27°C were excluded from analysis.

Table 11. Bedding bacterial counts (geometric mean; cfu/mL) in compost bedded pack (CB), low profile cross-ventilated freestall (CV), and naturally ventilated freestall (NV) barns in Minnesota and eastern South Dakota.

		Housing System[a]							
Season	Bacteria (cfu/mL)	CB		CV		NV		Overall	
Winter		Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
	Coliforms ('000's)	3	0.3-26	1	0.2-12	0.3[b]	0-2	1[a]	0.3-4
	Klebsiella	167	1-19596	0.8	0-87	6	0-681	9	0.6-141
	Environ. strep ('000,000's)	7	2-18	2	0.9-6	3	1-9	4	2-7
	Staph species ('000's)	0	0-9.5	0	0-9.5	0	0-9.5	0	0-4
	Bacillus ('000's)	0.8[b,y]	0.01-40	348[x,y]	7-17817	9,881[x]	185-526836	14	6-3505
Summer									
	Coliforms ('000's)	61	70-505	27	3-223	21[a]	3-171	32[b]	10-111
	Klebsiella	469	4-55188	44	0.4-4882	72	0.6-8515	114	7-1771
	Environ. strep ('000,000's)	1	0.5-4	5	2-12	6	2-17	3	2-7
	Staph species ('000's)	116	12-1101	0	0-9.5	0	0-9.5	5	1-18
	Bacillus ('000's)	798[a]	15-42571	59	1-3004	366	7-19542	258	26-2542
Overall									
	Coliforms ('000's)	14	2-74	6	1-33	2	0.4-12	6	2-16
	Klebsiella	280	5-14870	6	0.12-275	20	0.4-1089	31	3-288
	Environ. strep ('000,000's)	3	1-7	3	1-7	5	2-11	4	2-6
	Staph species ('000's)	11	2-53	0	0-4.9	0	0-4.9	2	1-6
	Bacillus ('000's)	25	0.9-67	143	6-3506	1,902	70-51593	197	28-1367

[a] a,b Significant between winter and summer within same bacteria species ($P < 0.05$).
x,y Significant between housing systems within season ($P < 0.05$).

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. Rendos et al. (1975) reported bedding culture results for used wood shavings of 6.6×10^6 for total coliforms, 8.6×10^6 for *Streptococcus* species, and 4.9×10^7 for *Staphylococcus* species. Rendos et al. (1975) results were higher than those collected from the CB barns, possibly due to the heating of the pack which may have killed some of the bacteria (Barberg et al., 2007). Harner et al. (2005) reported 4.9×10^5 for total coliforms, 4.3×10^5 for *Streptococcus* species, 3.6×10^5 for *Staphylococcus* species, and 6.7×10^4 for *Bacillus* on six dairies that used reclaimed sand. Bernard et al. (2003) had similar numbers of Bacillus and higher counts of coliforms, *Staphylococcus* species, and *Klebsiella* than current results. Bernard et al. (2003) and Harner et al. (2005) did not state any log transformations on the data which may have led to the discrepancies in bacterial counts for the sand bedded freestalls. It is believed that greater than10^6 cfu/mL of bacteria in the bedding are a risk factor for clinical mastitis in dairy cattle (Jasper, 1980). Compost bedded pack and CV barns averaged 3.1×10^6 and NV barns averaged 6.9×10^5 cfu/mL of total bacterial counts in the bedding. These results were lower than the threshold of potentially causing clinical mastitis; however, we recommend that producers clean teat ends thoroughly to maintain good milk quality.

Milk Bulk Tank Bacterial Counts

Results for the milk bulk tank samples are shown in table 12. Producer cooperation was needed to assist in collecting milk samples. During the winter three CV and NV barns did not return samples. During the summer one CV and one NV barn did not return the samples. Overall counts (geometric mean) were 168.7, 564.3, 32.3, and 7.5 cfu/mL for coliforms, non-ag *Streptococcus*, *Staphylococcus* species, and *Staphylococcus aureus*, respectively. There were no differences in bacterial numbers among housing systems for *Staphylococcus aureus*, non-ag *Streptococcus*, *Staphylococcus* species, and coliforms. There were no seasonal differences for bacterial counts, except for higher counts in the summer for coliforms ($P = 0.039$). A study of Pennsylvania herds found a mean coliform count of 70 cfu/mL (Jayarao et al., 2004). The CB and NV barns had milk bulk tank bacterial counts greater than 70 cfu/mL, which may be caused by inadequate cow preparation procedures at milking time.

Conclusions

Low profile CV barns had statistically higher aerial ammonia and hydrogen sulfide concentrations than NV and CB barns; however, ammonia and hydrogen sulfide concentrations were below the threshold that would affect cow performance or human/animal health. The CV barns in our study were near the minimum for recommended light intensity. We suggest that producers consider additional lighting and better light fixture maintenance to provide adequate lighting for workers and animals. The CV barns with evaporative cooling pads were 2°C 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.

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Table 12. Milk bulk tank bacterial counts (geometric mean; cfu/mL) in compost bedded pack (CB), low profile cross-ventilated freestall (CV), and naturally ventilated freestall (NV) barns in Minnesota and eastern South Dakota.

		Housing System							
		CB		CV		NV		Overall[a]	
Season	Bacteria (cfu/mL)	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Winter									
	Coliforms	63.7	6-735	2.1	0-145	54.0	0.1-20488	19.4[a]	1-252
	Non-ag Strep	911.2	138-6011	349.0	32-3820	277.9	20-3858	445.4	116-1704
	Staph species	26.1	2-443	32.5	0.2-4383	561.0	0.5-577059	78.1	4-1544
	Staph aureus	6.2	1.3-30.1	52.4	3.4-801	16.0	0.3-757	17.3	3.3-91.2
Summer									
	Coliforms	2597.5	179-37677	147.1	7-2930	266. 6	18-3885	467.0[b]	94-2333
	Non-ag Strep	846.8	125-5751	1447.7	173-12115	184.9	23-1460	609.7	188-1977
	Staph species	106.1	5-2360	12.3	0.4-395	15.4	0.7-342	27.2	4-175
	Staph aureus	2.0	0.4-11.5	6.0	.9-41.5	20.2	2.9-139.1	6.3	2.1-18.5
Overall									
	Coliforms	406.8	59-2801	17.7	1.3-251	119.9	4-3377	168.7	50-566
	Non-ag Strep	878.4	137-5617	710.8	88-5730	226.7	26-2009	564.3	227-1403
	Staph species	52.6	6-430	20.0	1-403	92.9	2-4149	32.3	11-94
	Staph aureus	3.6	1.1-115.	17.8	3.3-94.5	18.0	2.1-155.3	7.5	3.7-15.5

[a] a,b Significant between winter and summer within same bacteria species ($P < 0.05$).

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