Cow Comfort Issues in Freestall Barns

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Large scale dairies have become very popular in the past decade because of the adoption of new housing styles and the development of new production-enhancing technologies. These technologies allow producers to enhance labor efficiency, increase profits and improve the quality of life for both dairy owners and workers. The challenge to the managers of these modern large dairy herds is to economically achieve high milk yield without sacrificing animal health and welfare, deterioration of the environment, or human safety. The freestall barn has increased in popularity as a housing unit for cows and heifers throughout the industry. Properly designed and managed freestall barns provide a convenient method of managing dairy cattle and providing a comfortable living environment for those animals. This paper concentrates on design factors that emphasize cow comfort.

Freestall Barn Configurations

Freestall barns can be arranged in a variety of patterns, each of which has benefits and limitations. These tabled are patterned after those of Graves, 1995.

Two rows of freestalls with manger on one side

Benefits	Limitations
Adequate manger length for all animals to eat at one time	Higher draftiness in open-front versions
Adequate manger length to use self-locking headgates	Difficult to fit some sites for large herds
Narrow barn provides improved natural ventilation	May require more outside or covered lanes to access the parlor
Convenient manure removal	Feed may be exposed to precipitation
Convenient drive-by feeding	
Easy expansion	
Animals protected from sun, wind & precipitation	
Low cost per stall for unroofed drive	

Three rows of freestalls with manger on one side

Benefits	Limitations
Narrow barn provides improved natural ventilation	Not all animals can eat at one time
Convenient manure removal	Inadequate manger length to capture all animals in self-locking headgates
Convenient drive-by feeding	Higher draftiness in open-front versions
Easy expansion	Difficult to fit some sites for large herds
Animals protected from sun, wind & precipitation	Feed may be exposed to precipitation
Lowest cost per stall for unroofed drive	May require more outside or covered lanes to access the parlor

Four rows of freestalls with drive-through feeding

Benefits	Limitations
Adequate manger length for all animals to eat at one time	Wider barn may require higher side walls for good natural ventilation
Adequate manger length to use self-locking headgates	Highest cost per stall
Convenient manure removal	
Convenient drive-through feeding	
Easy expansion	
Animals protected from sun, wind & precipitation	
Convenient animal movement to parlor	
Feed protected from precipitation	

Six rows of freestalls with drive-through feeding

Benefits	Limitations
Convenient manure removal	Not all animals can eat at one time
Convenient drive-through feeding	Inadequate manger length to capture all animals in self-locking headgates
Easy expansion	Will require taller sidewalls for good natural ventilation
Animals protected from sun, wind & precipitation	Higher concentration of animals increases heat stress (heat & moisture levels) when ventilation rate is low in summer
Convenient animal movement to parlor	
Feed protected from precipitation	
Low to intermediate cost per stall	

Stall rows perpendicular to ridge line

Benefits	Limitations
Can have more stalls per square foot of building with alleys between rows only & outside feeding	May need to use outside feeding to have adequate bunk length
May be a way to fit more animals into an existing building	Manure removal not convenient
	May be difficult to move animals by group to parlor if crossover alley not provided
	May have fewest stalls per square foot of building if crossover alleys are provided on both ends of freestall rows
	Will be drafty in front stalls of open-front barn
	Will have blind alleys if no crossover alleys provided
	Outside feed bunk exposes animals & feed to sun, wind & precipitation

Two rows of freestalls with outside feeding

Benefits	Limitations
Narrow barn provides improved natural ventilation	May have a blind alley at end of pen
Convenient manure removal	Manure removal from yard may be problematic
Easy expansion	Difficult to fit some sites for large herds
Lowest initial cost freestall barn	Animals & feed exposed to sun, wind & precipitation
	End of barn stalls may be drafty
	Animal movement to parlor will be outside

Freestalls next to outside wall

(2-row tail-to-tail, 3-row, 4-row tail-to-tail, 6-row freestall barns)

Benefits	Limitations
More stalls per given barn length than face-to-face	Sun & precipitation more likely to enter stalls than face-to-face
Cows tend to prefer an outside row of stalls in summer	More cows have to walk further to feed than face-to-face
Timid cows not confronted from the front while in stall	Outside row draftier in winter
Manure in alleys less likely to freeze than in alley next to wall	Outside stalls need to be longer for lunge space
	Outside rows of stalls may block wind for natural ventilation

Face-to-face stall rows (2-row face-to-face, 3-row, 4-row face-to-face, 6-row)

Benefits	**Limitations**
Cows share head space – stall platforms shorter	Cows share head space – timid cows may avoid confrontation
Waterers can be longer across two rows of stalls	Animals tempted to lie down after milking instead of eating/drinking – no ability to limit access to stalls
Easier sidewall construction when no stalls near wall	Fewer stalls per row for a given building length in 2- & 4-row arrangements
More sidewall height can be opened when no stalls near walls	Manure in outside alley may freeze more quickly
Less sun & precipitation in stalls when no stalls near wall	Cows breathe into face of other cows (heat, moisture & pathogen concerns)

Outside feeding

Benefits	**Limitations**
Low initial investment	Higher feed losses from precipitation, heating & animal refusal
	Higher heat & cold stress in animals, contributing to reduced dry matter intake with consequent reduction in milk production
	Manure exposed to precipitation, contributing to contaminated runoff
	Worker exposure to weather

Inside feeding

Benefits	**Limitations**
Low feed loss	Higher initial investment
Low animal stress	
No contaminated runoff	
Weather protection for those working inside (animal treatments, animal observation, manure removal, etc.)	

Freestalls

To support the high production levels expected of or modern dairies, facilities must be designed to provide a comfortable place for cows to lie. Designs must also consider the initial and on-going cost to maintain the stalls. These objectives often are antagonistic and the producer must select a design that considers both criteria. Current research has shown stall usage increases with increased stall size and the use of certain stall base materials. The task for the producer is to weigh the value of the expected increased milk production, lower health costs, and/ or increased longevity in the herd against the extra costs incurred.

Lactating Dairy Cow Daily Time Budget

Research by Grant, 2003, shows the daily time budget for a lactating dairy cow to include 10-12 hours lying, 3-5 hours eating, 30 minutes drinking and 2-3 hours during milking. High producing cows have been shown to lie up to 14 hours per day and that for each additional hour a cow spends resting an additional two pounds of milk per day can be expected. This is the main reason why much of the current cow comfort research on stall size, divider design, and stall surfaces use the amount of time cows spend lying as an indicator of cow comfort.

How big are your cows?

Cows will use comfortable stalls because correctly sized freestalls are easy for the animal to get up and down and they have a comfortable surface to lie on. To support labor efficiency, stall size should encourage animals to lie straight in the stall with their udder and legs completely on the stall platform, but with their rump over the back of the stall so manure will fall in the manure alley and not on the stall surface. The sizing of freestalls is determined by the animal's size and should be built to accommodate the larger animals in a group. Anderson, 2003, has found that rump heights and hook bone widths are useful to estimate several other body dimensions (Table 1). He suggests that you determine the size of animals by measuring a large representative group of animals in your herd and using data to estimate the following dimensions.

Body Dimension	Normal Cow	Dimension Relationship
Rump Height - Mature	Median 60”	
Rump Height – Lactation 1	Median 58”	
Hook-bone width	26”	
Nose-to-tail length	102”	1.6 * rump height
Resting imprint - length	72”	1.2 * rump height
Resting imprint - width	52”	2.0 * hook-bone width
Forward lung space	24”	0.4 * rump height
Stride length when rising	18”	0.3 * rump height
Stance – front-to-rear feet	60”	1.0 * rump height
Wither (shoulder) height	60”	1.0 * rump height

Table 1: Body dimension, example measurements for mature Canadian Holstein, and ratios to height and hook-bone width.

Cow Comfort

Although ‘cow comfort’ has become a buzzword among dairy producers and professionals, scientific research is limited. Recommendations for freestall dimensions vary widely and make the decision on what to build very confusing. Weary and Cassandra suggests scientific research should be based on three factors: 1. does the housing cause injuries to the animal: 2. what types of housing do the animals prefer; and 3. how does the housing affect the animals behavior. In the following pages we will attempt to site some of the current research relating to these issues.

Skin Lesions on the Hock

Mowbray, et al., 2003, showed that hair loss on the hock joint was affected by different stall base types. When geotextile mattress covered stalls with 1.2" of kiln-dried sawdust bedding (mattress) was compared with deep-bedded sand based stalls with 8" of washed river sand over a dirt base (sand), it was found that skin lesion location changed. Hair loss and skin breakage was higher at the hock joint for cows housed in mattress stalls and higher on the point of the hock for sand stalls. The suggested cause for lesions is friction between the leg and the mattress surface, and contact with the rear curb in sand stalls.

Freestall Design – Manure Curb Height

The key freestall dimensions to consider are curb height, stall width, stall length, neck-rail height, and freestall divider mounting specifications. If curbs are too low, manure may enter the stall when manure it being removed from the barn and if too high, cows will be reluctant to back out of the stalls. A curb height of 10" is normally recommended, but often will be 9.5" if a 2"x10" plank is used to form the curb. Some people advocate a lower curb height. For example, Cook and Nordlund, 2004, recommends an 8" curb and moving the neck rail back the width of the curb to force cows to stand in the perched position with sand based stalls. They are not concerned with cows perching since their work indicates cows do not spend prolonged times standing half in and half out of sand stalls and the elevation of the front feet will be less with the lower curb.

Construction of the manure curb differs for stalls filled with bedding materials (sand, manure solids, lime, etc.) than from flat surface stalls that are covered with a cushion of some type (mattresses, mats, waterbeds, etc.). Manure curbs for sand stalls normally are 4-6" wide and are used to hold the bedding material in the stall. Since the level of the bedding material changes with the mount of material in the stall, the manure curb is often chamfered in the direction of the cow to prevent the cow from having to lie against the sharp edge when the bedding level is low. With flat surface stalls the height of the added cushion needs to be considered. Having a 10" curb with a 4" mattress in effect becomes a 14" curb. Most recommendations for this total curb height is between 8 and 12" .

Freestall Design – Stall Base Slope

Normal recommendations have been to have stall bases constructed with a slope of 2-3% from the manure curb to the brisket locator. This has been done because cows prefer to lie uphill and to allow any liquids (urine, milk, rainwater, etc.) entering the stall to drain away from the stall bed and to the manure alley. Sand stall are often filled fuller in the front than in the back to provide this upward slope. If stalls ever become lower in the front that the back they will cause problems for the cow attempting to rise. Field observation suggests that excessive slope can cause cows to lie with their feet protruding into the manure alley.

Freestall Design – Cow Space Needs

Figure 1 shows the motion of a cow rising or reclining. It shows the three areas that must be provided within the freestall: body space, head space and lunge space. Different authors have suggested the proper length of each of these based on their work. Obviously these values vary with the size of the animal.

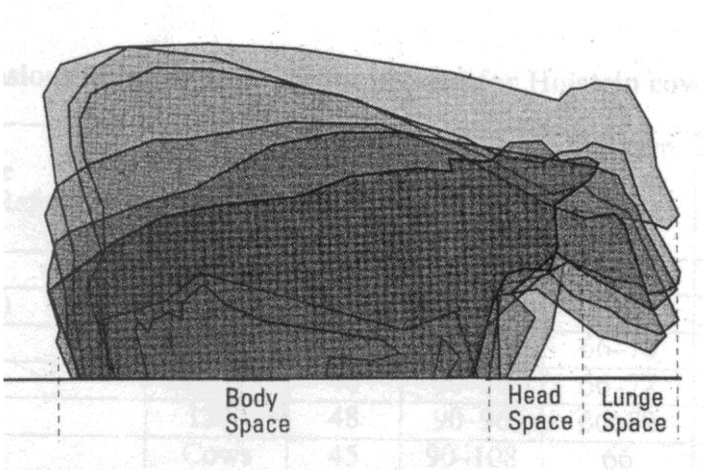


Figure 1: Space envelop for rising and resting cow.

Cow Weight:	1200 lb	1450 lb	1650 lb
Body Space	62-64”	66-68”	70-72”
Head Space	17”	18”	19”
Lunge Space	14”	15”	16”
Total Stall Length-Open Stall Front	6.7 to 7.2’	7 to 7.5’	7.5 to 8.2’
Total Stall Length -Closed Stall Front	7.7 to 8.2’	8 to 8.5’	8.5 to 9’

Open Stall Front – cows can lunge through the stall front
Closed Stall Front – cows can not lunge through the stall front

Table 2: Suggested freestall dimensions for various size cows (McFarland 2003)

Cow Weight:	1400 lb	1600 lb	1800 lb
Body Space	68-70”	70-72”	72”
Total Space-Open Stall Front	8.5’	9’	9’
Total Space-Closed Stall Front	9’	10’	10’

Table 3: Suggested freestall dimensions for various size cows (Cook 2004)

Tables 2 and 3 above show some of the variation in current recommendations. Both show the need for stall length to increase as animal size increases, but assume different weights. It is commonly accepted that the average Holstein cow in the U.S is larger than a decade ago, and lends credibility to increasing stall sizes. Genetics, nutrition and the use of custom heifer raising possibly have caused this increase in size. When making a decision on stall size you should know the relative size of your cows and how you plan to house them. Making the stall size the same for all pens of a new facility allows the manager flexibility on how to use the pens, but complicates the decision on what size stall to build. Building all stalls to meet the needs of your largest cows will result in smaller cows using the stalls incorrectly, but making stalls too small for large cows will make them uncomfortable.

Freestall – Length of Stall to Brisket Locator

Brisket locators, previously know as brisket boards, are placed in the stall to position the cow when she lies down. The base of the brisket locator is normally placed 66-72" from the manure curb and defines the amount of space a cow has for her body space. Experience has shown that 66" stall beds and high brisket boards have not provided enough space for large cows and they lie with their rump extended past the manure curb and sometimes even have their udders straddled across the edge of the manure curb. Originally these locators were made of wood placed at an angle to accommodate the shape of the animal as she rested the front of her body against them. Often the space in front of the brisket board was filled with concrete to prevent a build-up of bedding materials. Less rigid materials, which allow some flexibility as cows move, are now being used in place of boards and have resulted in the use of this new term. Anderson observed animal behavior and suggested that proper stall should allow cows to stretch their feet forward when lying down and have the ability to extend their feet into the space in front of the brisket locator when rising. He observed that a cow usually swings her foot high enough to clear a 4" obstacle and suggested this be the maximum height of a brisket locator above a mattress or sand bedding. He discouraged the use of brackets to support the brisket locators from the lower pipe of the stall divider because it obstructed the extension of the cow's foot. In addition he suggested a 5" space should be provided between the top of the brisket locator and the bottom of the stall divider to prevent leg entrapment of the animal. This recommendation is easy to implement with mattress stalls since the brisket locator can be attached to the stall surface, but becomes a challenge with sand based stalls that often do not have a base to attach them. These recommendations lead to the new recommendation relating to stall design in that the surface in front of the brisket locator should not be elevated above the stall surface to allow the cow space for her feet.

Freestall Design – Total Stall Length

As mentioned earlier total stall length should provide body space, head space and lung space. Tables 2 and 3 reflect different author's view of this need based on differences in cow sizes they reference. Open front stalls allow a cow to extend past the stall perimeter when rising either by placing their head in an adjacent stall in a head-to-head arrangement or with extra space provided in front of the stall for single rows of stalls. Closed front stalls have some type of barrier that prevents the cow from lunging outside the perimeter of the stall. If stalls are too short to allow cows to lunge forward, a stall divider that allows the cow to the side should be selected. Cows normally prefer to lunge forward and if allowed to do so often will lie straighter in their stall. Cows that are forced or prefer to lunge to the side often lie at an angle in the stall which results in more manuring in the stall and the increased problems associated with it. Anderson, 2003, reported that at a study farm with 16', open front, head-to-head freestalls, cows lunged diagonally 34% of the time when the facing stall was empty and 81% of the time when the stall was occupied. At another farm, cows lunged diagonally 68% of the time with the original 8' closed front stalls and 44% of the time with modified stalls that had open fronts and loops with 38' wide side openings. This information supports the decision to build closed front stalls longer than 8' and the choice of a stall divider which allows diagonal lunging in case a cow is concerned with lunging into an occupied stall.

Freestall Design – Neck Rail Placement

Neck rails are placed in the front of the freestall (Figures 2 and 3) to position the animal when she enters the stall. These normally are placed directly above the base of the brisket locator which provides sufficient space for the animal to stand in with all four feet in the stall and positions the cow so she defecates in the manure alley. For higher neck rails the neck rail should be moved back toward the manure curb about 2" to reflect the shape of the cow. Cook's current recommendation for sand based stalls is to shorten this distance by the width of the manure curb, forcing cows to perch rather than stand with all four feet in the stall. This recommendations is based on observation that cows normally will not stand on the manure curb, which encourages the cow to place her hind legs inside or outside of the manure curb. Having cows stand with all four feet in the stall and the back feet inside the manure curb leads to increased manuring in the stall, dirtier stalls, and increased labor to maintain the stalls. Neck rail mountings should allow them to be moved forward or backward as experience shows the stall bed is too short or too long, based on an excessive animal perching or frequent manuring in the stall.

Recommendations for neck rail height above the stall surface changed the most in recent years. Placement of the neck rail too low makes it difficult for animals to rise without hitting the rail and discourages stall use. Previous recommendations specified a minimum distance between the stall surface and the bottom of the neck rail to be 42". Current recommendations are for neck rails be mounted 48-50" above the stall base surface. Proper placement of neck rails is easier in mattress based stalls since they have a constant surface level and the neck rail height is defined as the distance above the stall surface, whereas surface elevation in sand stalls depends on the amount of sand in the stall at any one time, so neck rail height is measured from the top of the manure curb.

Recent work by Fulwider and Palmer (2004) has shown that the percentage of time cows lie in a stall increased significantly when the neck rail was raised from 45" to 50" in a mattress based freestall barn (Table 4). A fifty cow pen had half of the stalls modified and the other half left unchanged. Stall usage was recorded, before the stall changes and a 5-week acclimation period was allowed before stall usage was again measured. There was no significant change in stall usage for the existing stalls, but a significant increase in the percentage of stalls with a cow lying in the modified stalls was observed (40.0 to 51.4%). This research was done in a 4-row, tail-to-tail barn, with 46" wide and 8' long stalls, which indicates stall usage can be increase by changing neck rail height, etc. without changing stall width or length. To increase the neck rail height new stall divider types were installed and the stall divider mounting rails in the front of the stalls were removed. Field experience has shown that removing horizontal mounting pipes (chin clippers) often will increase stall usage because cows dislike hitting these rails as they attempt to rise. The increase in stall use was significant and demonstrates the importance of proper stall design, but does not prove the neck rail height alone caused the increase.

	Before Neck Rail Change 1-29 to 2-26-03	After Neck Rail Change 4-03 to 5-01-03
Average Stocking Density	96%	94%
45" Neck rail before and after - Percent of stalls with cows lying	42.1[b]	43.8[b]
45" Neck rail before , 50" after - Percent of stalls with cows lying	40.0[b]	51.4[a]

[a,b] Percentages with different superscripts differ ($P < .05$).

Table 4: Effect of neck rail height on the percentage of freestalls with cows lying in them.

Freestall Design – Stall Width

Stalls should be wide enough to allow animals to recline and rise easily. If stalls are too wide, animals will tend to stand and lie at an angle in the stall. Smaller cows often will lie backward in the stall which causes manure to be deposited in the front of the stall. Both of these situations can lead to dirty cows and additional labor to clean stalls because animals will deposit manure on the stall surface. For the average mature Holstein herd, 46-48" wide stalls often meet these requirements the best. Larger stalls, 48-50" wide, may be considered for extremely large or pregnant dry cows. Often 48" stalls are built as a convenience to the builder, whereas, 46" stalls would offer the advantages mentioned, plus allow more stalls per barn.

Cows prefer to lunge forward when rising, because transferring their weight forward allows them to lift their hindquarters more easily. Eight feet of effective stall length has been recommended for mature Holstein cows. Since the average size of cows has increase using 8' open front stalls or 9' closed front stalls seems to be adequate. Some people are advocating stalls longer than these dimensions to provide a situation where cows have complete freedom to lunge forward. Anderson's recommendations based on work with large Canadian Holsteins are often the basis for these recommendations.

Tucker et al., 2004, reported the effect of cow lying and standing behavior and milk production (Table 5). In this research 42", 46" and 50" wide stalls were compared. The number of lying events in 24 hours, the duration of lying bouts, total lying times, and milk production were compared. For all these factors there was a significant advantage of the 46" stall over the 42" stall, but no advantage of the 50" over the 46" stall. Increasing stall width decreased the amount of time cows were half in and half out of stalls and increased the amount of time they stood with all four feet in the stall. Based on this work the value of going to 50" stalls may be challenged. Observation also suggests that if stalls are too wide cows tend to stand at and angle in the stall which results in increased manuring in the stall and it's associated problems.

Stall width:	42” Stall	46” Stall	50” Stall
Lying events (number per24 h)	12.3	11.9	11.9
Duration of lying events (h per bout)	1.1	1.2	1.2
Total lying time (hrs per 24 h)	12.3	13.0	13.0
Perching (min per 24 hr)	85	66	58
Standing four feet in stall (min per 24 h)	53	50	68
Total time standing in stall (min per 24 h)	138	116	126
Milk production (lb per 24 hr)	103	101	102

Table 5. Lying and standing behavior and milk production for three stall widths (n=27)

Freestall Divider Design

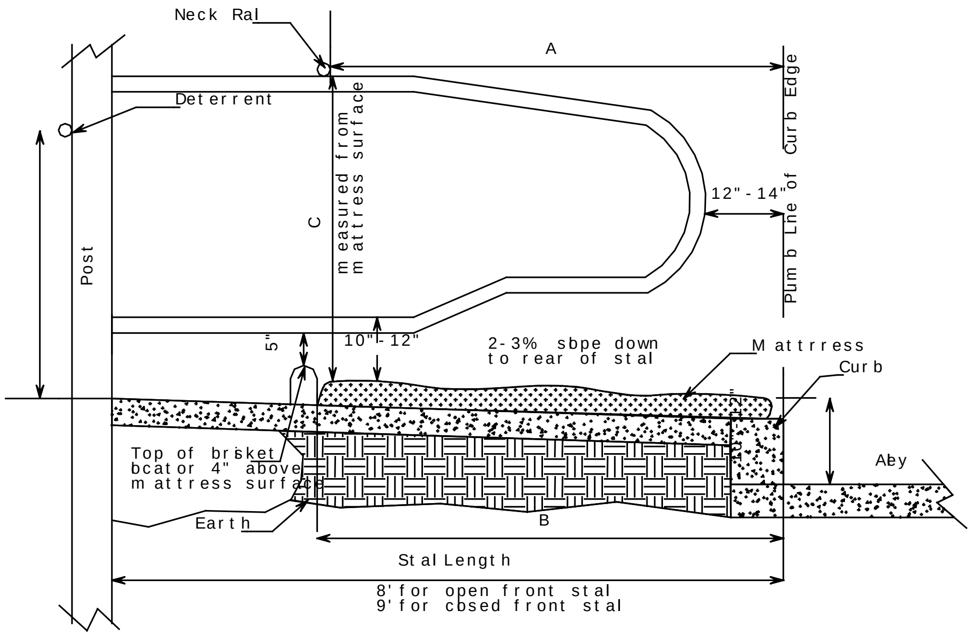
There are many different freestall stall divider designs currently being marketed, and they are often referred to by names such as side-lunge, wide loop, straight loop, etc. Whichever stall divider type is selected, its length should allow 14” space between the end of the divider and the manure curb once the stall dividers are mounted (Bickert et al., 2000). Allowing additional space encourages cows to walk along the backs of the stalls and/or to enter another cow’s space. Allowing less space may result in cows hurting themselves as they enter the stall hitting the divider. In practice 12-14” appear to work very well to eliminated these problems. Remember, barns having different stall lengths, should have different length stall dividers.

Another important dimension is the distance from the top of the stall divider’s bottom rail to the stall base surface. If the stall divider provides sufficient space for the animal’s head, then the bottom rail needs to be high enough to discourage the animal from crawling over it. Field observation suggests this bottom rail should be at least 12” above the stall surface. In the past producers have reported dissatisfaction with extremely wide loop designs because cows got jammed in them and they tended to encourage cows to lie at an angle in their stall. This was probably caused by the divider being mounted too low which allowed the cow to craw over the lower divider bar. Current stall design recommendations with their higher neck rail placement and the associated raising of the lower rail of the divider appears to have solved this problems. A second consideration with divider is the amount of space provided at the rear of the stall below results in cows lying at an angle in the stall. Choosing a divider which has it’s lower rail extend straight past the brisket locator 12’-24’ before rising to provide space for the cows hook bones will minimize this problem.

Barns with rows of head-to-head stalls allow animals to lunge into the stall in front of them. This feature saves space, but can also lead to animals exiting through the front of the stall or being jammed between neck rails as they stand and try to walk through. This is especially true of he newer designs with higher neck rail placements. To discourage this a deterrent (strap, cable or pipe) may be placed between the rows of stalls. Such a pipe must be high enough to allow the cow to lunge forward unobstructed, but low enough to prevent her from exiting through the adjacent stall. Current recommendations specify this deterrent to be placed 40” above the stall base surface on 8’ stalls and 34’ for 9’ stalls.

Mattress Based Freestall Design

Figure 2 is an example of a mattress based freestall for average sized Holstein cows. Notice how dimensions vary depending on the type of animal (First Lactation, Milking Cows (Lactation > 1), and Dry Cows). These are only guidelines, but consider the fact that freestalls that are too large cost extra money to build, result in dirty cows, and/or extra labor to keep stalls clean. Stalls that are too small lead to increase injuries and culling rates and the potential for loss of milk production because cows do not use the stalls as much as otherwise would be possible.



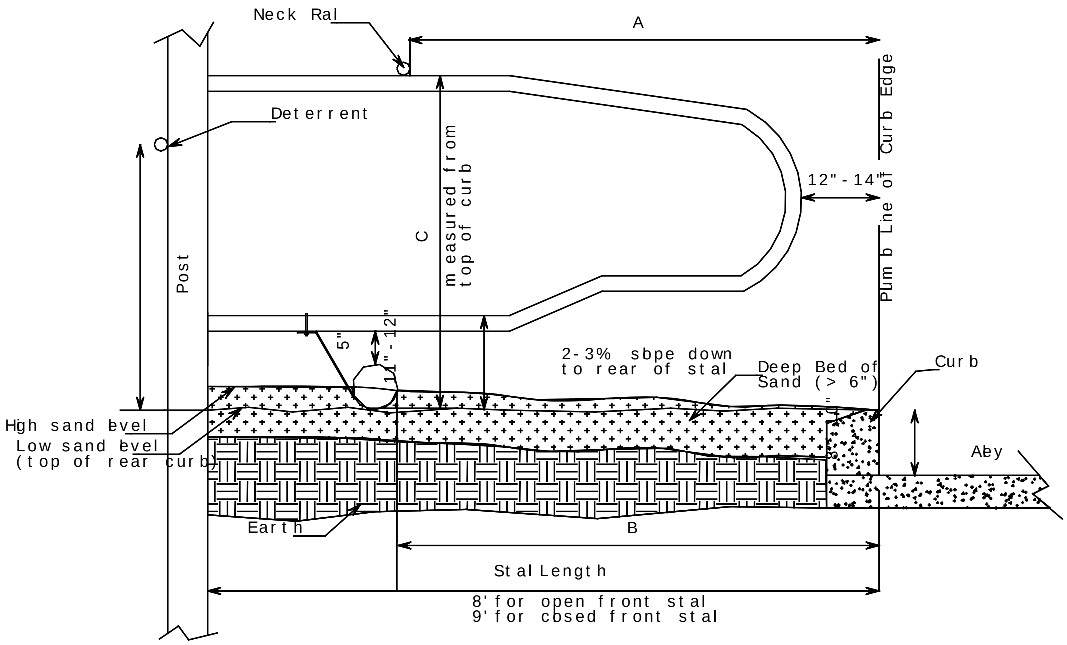
Average Holstein	Weight	A	B	C	Width
First Lactation Cow	1300 lb.	68"	70"	48"	46"
Milking Cow	1500 lb.	70"	72"	50"	46"-48"
Dry Cow	1600 lb.	70"	72"	50"	48"

Example Mattress Based Freestall Design
for Average Sized Holstein Cow

Figure 2: Example of a mattress based freestall for average sized Holstein cows.

Sand Based Freestall Design

Figure 3 is an example of a sand freestall for average sized Holstein cows. Notice how dimensions vary depending on the type of animal (First Lactation, Milking Cows (Lactation > 1), and Dry Cows). These are only guidelines, but consider the fact that freestalls that are too large cost extra money to build, result in dirty cows, and/or extra labor to keep stalls clean. Stalls that are too small lead to increase injuries and culling rates and the potential for loss of milk production because cows do not use the stalls as much as otherwise would be possible.



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Bedding Material Choices

Freestalls are often thought of as having two components, a stall base constructed of clay, concrete, wood or some other material and a bedding surface. With deep sand freestalls, sand supports both functions. Whatever components are selected, freestalls should conform to the shape of the cow when she is resting, provide cushion when she is reclining and traction when she is rising. It is recommended that the stall surface be 2-3% higher in the front than in the back of the stall. This discourages forward movement while resting and improves stall drainage. Many people feel cows actually prefer to lie up hill. One situation to avoid is stalls that are lower in the front than the back. Cows have difficulty getting up under these circumstances. Excessive stall slope may also cause cows to lie incorrectly.

Many different freestall combinations have been tried over the years with different costs and results. Cows dislike concrete-based stalls unless a thick bedding surface is maintained on top of them. Straw, sawdust, manure solids, and other organic bedding surface materials have been used successfully over concrete bases, but their cost is sometimes prohibitive. Wood-based stalls have not been successful because wood rots and gets slippery when wet. Clay-based stalls can provide cow comfort but require a large maintenance effort since cows dig large holes in the stalls. Producers have used rubber tires in freestall bases. Cows seem to like tires in stalls, and bedding requirements are decreased, but getting the tires installed properly is very important. Tires should be of the same size, placed tight together and carefully packed with material to hold them in place. Tires can make it difficult to remove soiled bedding. Different types of rubber mats have been tried over the years with mixed results. Some get slippery and promote hock damage, and others have deteriorated in a short period of time.

Mattress-based stalls currently are very popular, and for most producers the choice of freestall bases is between sand and mattresses. Mattress-based stalls normally have some rubber particles, water, or other type of filler that conforms to the animal's body and may offer an insulating effect during cold weather. They have a cover that provides animal traction, may be waterproof, and is durable enough to withstand animal traffic. The initial cost of mattress-based stalls is normally $50-100/stall, and their expected useful life is between 4 and 7 years. Mattress-based stalls need to have some type of absorbent bedding applied to them, but the amount is less than deep-bedded stalls over concrete. The initial investment in sand-based stalls is low, but the labor to fill and maintain them, the cost of the sand used, and the adverse effects the sand has on manure handling and storage results in a high maintenance cost.

Sand versus Mattresses - Performance and Producer Satisfaction

A survey of Wisconsin producers who increased herd size by at least 40% from 1994 to 1998 (Table 6) showed no significant difference in DHI milk production or somatic cell counts between those using sand and those using mattresses after their expansion (Palmer and Bewley, 2000). Producers using sand seemed to be more satisfied with cow comfort, and less satisfied with manure management and bedding than those using mattresses. Sand users reported significantly higher satisfaction scores for cow cleanliness and hock injury, whereas mattress users reported significantly higher satisfaction with bedding use and cost and manure management. Culling rates, although not significantly different, showed a slight numeric advantage to sand users.

Freestall Bedding Type	Mattresses	Sand
Number Herds	69	145
DHI 1998 RHA Milk(lbs)	22,519	22,539
Avg. Linear SCC	2.88	2.80
Culling Rate (%)	34	32
Cow Cleanliness*	4.12	4.47
Hock Damage*	4.22	4.72
Bedding Use and Cost*	4.25	3.95
Manure Management*	4.32	3.43

* Average satisfaction reported on a scale of 1 (very dissatisfied) to 5 (very satisfied)

Table 6 Average production and producer satisfaction values of herds using mattresses or sand bedding.

An Iowa study, which was designed to evaluate six different freestall surfaces, found that stalls ranked differently by week of trial, with cow preference switching between sand and mattresses (Thoreson,2000). Sand ranked highest in the summer, but usage declined from summer to winter.

Other research conducted in Europe demonstrated that cows showed definite preference for some types of mattresses and that cow preferences changed over time (Sonck and Daelemans, 1999). It was suggested that cows need time to adjust to some types of mattresses and other mattresses get harder and less comfortable over time.

Table 7 (Palmer, 2003) shows that stall base type affects cow preference. This study reported the stall usage for a 4-row freestall barn with 100% stocking rate. Observations of cows lying or occupying stalls (standing or lying) were recorded for a nine month period. Sand and mattress-I (Rubber filled) based stalls consistently had larger stall use percentages; concrete and soft rubber mats consistently the lowest percentages; and mattress-II (Foam filled) and waterbeds percentages were intermediate. The sand based stalls had the highest overall lying percentage, but mattress-I and mattress-II had the highest stall occupied percentages. Cows appear to prefer to stand on soft surfaces provided by mattresses or soft rubber mats to sand stalls or concrete alleys. The lying percentage advantage of sand over mattress-type-I (68.7% > 65.2%) was small compared to the stall occupied advantage of mattress-type-I over sand (88.3% > 79.0%). This suggests cows like to lie down on both stall bases, but prefer to spend non-lying time standing in mattress-type-I based stalls rather than on concrete manure alleys. Some stall base types were consistently inferior to others. Lying percentages for concrete and soft rubber mats were always below the average lying percentages. Mattress-I based stalls consistently ranked higher than mattress-II for lying and stall occupied percentages, which indicates not all mattresses are equally desirable to cows and making general statements about "mattresses" may be misleading. The length of time cows are exposed to the different stall bases affects lying and occupied percentages. The waterbed based stalls required a longer adaptation time whereas use of soft rubber mat based stalls in this trial decreased over time.

	Soft Rubber Mat Type I	Waterbed	Mattress-I (Rubber Filled)	Mattress-II (Foam Filled)	Concrete	Sand	Average
% Lying	32.9	45.4	65.2	57.4	22.8	68.7	51.0
% Standing	24.6	7.9	17.0	20.7	8.8	3.3	12.1
% Occupied	64.8	61.6	88.3	84.1	38.7	79.0	70.1
No. Obs.	6727	6727	6727	6727	7688	13454	

Table 7. Cow Preference for different stall base types "Experiment 1" for 4-row barn with 100% stocking density.

Cook et al., 2004, studied the differences in behavior of nonlame cows, slightly lame cows, and moderately lame cows in 6 free stall barns with sand bedding (SAND) vs. 6 free stall barns with rubber-crumb geotextile mattress surfaces (MAT) were documented in Wisconsin dairy herds. All lactating cows in the 12 herds were observed and given a locomotion score based on a 4-point scale: 1 = nonlame, 2 = slightly lame, 3 = moderately lame, and 4 = severely lame. Herd least square means ±SE for prevalence of clinical lameness (locomotion scores = 3 and 4) were 11.1 vs. 24.0 ± 1.7% for herds using SAND vs. MAT surfaces, respectively (Table 8). Herd size, stocking density, rolling herd average milk yield, annual turnover rate and mean ambient temperature on visit day were not statistically different for there MAT or SAND herds. Culling rate although not statistically different showed a numeric advantage for SAND herds (36.5 vs 28.8) which is consistent with the results reported by Bewley et al. 2003. The major finding was that the average herd prevalence of clinical mastitis was significantly higher in MAT herds than SAND herds (24.0 vs 11.1), where clinical lameness was defined as cows having a locomotion score of 3 or 4.

	MAT	SAND	SE	*P*
Herd size (no. cows)	304.7	297.7	30.2	0.87
Cows in pen (no.)	77.3	95.8	7.8	0.12
Stocking rate (high pen %)	107.8	108.0	5.0	0.98
Rolling herd average milk yield (kg)	11,241	11,912	547.5	0.41
Annual turnover rate (%)	36.5	28.8	2.9	0.09
Mean ambient visit temperature (°C)	7.2	8.3	0.4	0.73
Herd prevalence of clinical lameness[1] (% all milking cows)	24.0	11.1	1.7	<0.001

[1]Clinical lameness includes cows that had locomotion scores of 3 and 4 and were either moderately or severely lame. Locomotion score scale: 1 = nonlame, 2 = slightly lame, 3 = moderately lame, 4 = severely lame.

Table 8. Least square means and SE of herd level background data for 6 herds using mattresses (MAT) and 6 herds using sand bedding (SAND).

Subsets of 10 cows per herd with locomotion scores of 1 to 3 were observed via video cameras for 24-h periods (Table 9). There was no difference is the lying time between MAT and SAND barns (11.66 vs 12.01), and cows in MAT herds spent more time standing in free stalls per day than cows in SAND herds (3.44 vs 1.83) which agrees with the findings of Fulwider and Palmer, 2003. Cows in SAND barns were also found to spend more time feeding than MAT barns (4.65 vs 4.08) and had a higher number of stall use sessions (7.57 vs 6.92). The proportion of lying bouts greater than 60 minutes was higher for SAND herds than MAT herds (0.61 vs 0.49).

Daily activity	MAT	SAND	*P*
Time lying in stall	11.66	12.01	0.56
Time standing in stall	3.44	1.83	0.002
Time up in alley	2.27	2.34	0.66
Time up feeding	4.08	4.65	0.03
Time up milking	2.58	3.21	0.37
Number of stall use sessions	6.92	7.57	0.03
Proportion of lying bouts >60 minutes	.49	.61	0.03

Table 9. Mean daily activity patterns (h/d) for 60 cows in 6 herds using mattresses (MAT) and for 60 cows in 6 herds using sand bedding (SAND).

Figure 4 shows how daily activity patterns of cows vary by locomotion score between MAT and SAND herds. Activity patterns are consistent in cows in SAND herds across all locomotion scores with little variation. Nonlame cows in MAT herds behave similar to all cows in SAND herds, apart from a small but significantly higher time up in stall. In contrast, cows in MAT herds that are slightly lame and moderately lame show the modifications in behavior. Differences in standing times were 0.73 h/d for cows that were not lame, 2.32 h/d for cows that were slightly lame, and 4.31 h/d for cows that were moderately lame in MAT herds compared with equivalent cows in SAND herds. In MAT herds, the increase in time spent standing in the stall in moderately lame cows was associated with a significant reduction in stall use sessions per day, which impacted daily lying time. As time standing up in stall increases, time spent performing other activities is reduced. Time up milking is largely unchanged, but time up in alley is significantly reduced ($P < 0.05$). Moderately lame cows in MAT herds had significantly ($P = 0.003$) fewer mean number of stall use sessions at 0.62 compared with moderately lame cows in SAND herds at 8.50.

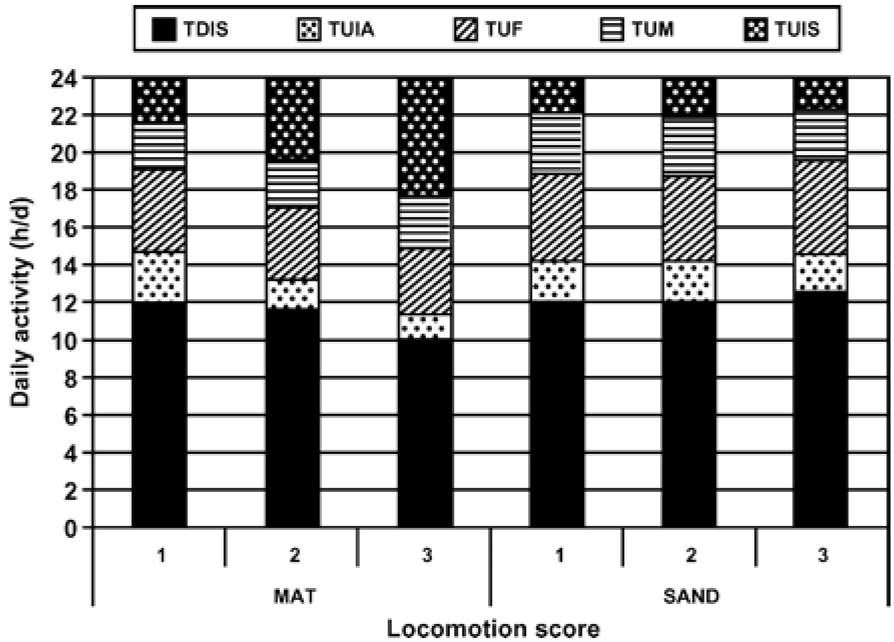

Figure 4. Daily time budgets for time lying down in stall (TDIS), time standing up in stall (TUIS), time up in alley (TUIA), time up feeding (TUF), and time up milking (TUM) in 73 nonlame (locomotion score = 1), 37 slightly lame (locomotion score = 2), and 10 moderately lame (locomotion score = 3) cows in 6 MAT (rubber crumb-filled geo-textile mattress free stall) and 6 SAND (sand-bedded free stall) herds.

Table 10 shows the results of a second experiment conducted in the same barn as Experiment 1 (Fullwider and Palmer, 2003). Two different mattress types and three different soft rubber mat types replaced the sand, concrete and waterbed stall bases. Cow preference was strongest for foam and rubber filled mattresses. Cow preference for the two mattress types previously tested and which had been preferred now was intermediate. These two mattress types were installed approximately three years before the other stall bases, so it is not possible to determine if the new mattress types were superior or if the decrease in cow preference of the existing two types was due to an aging effect. Rubber mats were consistently used the least. Differences in stall use existed between different manufacturers' foam and rubber filled mattresses. Visual inspection shows differences in deterioration and surface levelness of the different products over time. These factors can influence the life expectancy of each product and should be considered along with cow preference when making a buying decision.

Freestall Maintenance

One key point that must be emphasized is that no matter what stall type is selected, maintenance of the stalls is critical. Mattress stalls should be bedded frequently, preferable daily, to insure there is a layer of bedding on the stall surface at all times. Sand stalls should be filled frequently to maintain a sand level even with the top of the manure curb at the back at all times. This usually requires the sand stall surface in the front of the stall to be approximately 5 inches higher immediately after filling and no lower than the level of the manure curb when refilling is needed. Sand stalls should be leveled at least once per day. Any manure deposited in the stall should be removed every milking no matter what type of stall base is selected.

Stall Base	Exp 2 % Lying 6-19/12-17	Exp 1 % Lying (Ranking)	Exp 2 % Occupied 6-19/12-17	Exp 1 % Lying (Ranking)
Mattress-Type III (Foam Filled)	62 %[a]		91 %[a]	
Mattress Type IV (Rubber Filled)	59 %[ab]		84 %[b]	
Mattress Type I* (Rubber Filled)	57 %[b]	65 % (1)	85 %[b]	88 % (1)
Mattress Type II* (Foam Filled)	52 %[c]	57 % (2)	81 %[b]	84 % (2)
Soft Rubber Mat Type II	51 %[c]		73 %[c]	
Soft Rubber Mat Type III	43 %[d]		64 %[d]	
Soft Rubber Mat Type IV	42 %[d]		65 %[d]	
Average	52 %	51 %	78 %	70 %

[a,b,c,d] Percentages within rows, lying & occupied analyzed separately, different superscripts significantly differ ($P < .05$).

Table 10: Cow Preference for different stall base types “Experiment 2” for 4-row barn with 100% stocking density.

Use of Rubber Alley Mats

Previous work by Fulwider and Palmer, 2003, indicated that cows lie down as much time in well designed mattress stalls as in sand stalls, but spend more time standing in mattresses based stalls. Cook et al., 2004a found the same to be true (Table 9). Different reasons have been proposed to explain these phenomena. In the fall of 2003 rubber alley mats (RAM) were installed over all alleys in the same pen as stall preference studies had been conducted earlier. Table 11 shows the effect of rubber alley mats on stall use (Fulwider and Palmer, 2003). Stall use was recorded for 31 days before the RAM’s were installed. A three week acclimation period was given to allow cows to adjust their behavior patterns and then stall activities were recorded and the results compared to the before vales. No change in the amount of stalls with a cow lying in them was found, but the percent of stalls with cows standing in them decreased significantly. This was interpreted as cows preferring to stand on soft surfaces. In other words, cows preferred to strand in soft stalls when hard concrete floors were the alternative.

	Before RAM's 8-10 to 9-11-03 (97% Stocking Density)	After RAM's 10-1 to 10-23-03 (92% Stocking Density)
% of Stalls with Cows Lying	46[a]	48[a]
% of Stalls with Cows Standing	23[a]	10[b]

[a, b]Means within rows with the same letter are not significantly different (P<.05)

Table 11: Effect of rubber alley mats (RAM) on stall use.

Alleys

Alleys are used by the animals to move freely within the barn to access stalls, water, and feed and to seek comfortable areas of the barn. Alleys are used by operators to collect manure and move animals around within the system. Alleys must be designed for comfortable movement of animals, safety and convenience of operators, and access by equipment. To be comfortable for cows, alleys must have slip-resistant surfaces and enough width to provide ease of movement and personal space. Cows need to be able to back out of freestalls while other cows are standing at the bunk to eat. Cows need to be able to walk behind cows standing at the bunk to eat and to walk behind those standing at a waterer. The values in Table 12 are minimums which allow for these easy movements. Use the recommended values for maximum cow comfort. When cows are being herded (to parlor), alleys must be wide enough to keep the group moving at a reasonable pace. Alleys must be wide enough so one or two cows stopping does not halt the group. When animals must be herded, use the values in Table 13 to select the alley width. Alleys where animals are herded include those within the housing unit, including the crossover at the end of the stall rows and the travel lane to the parlor. Initial cost can be reduced by making lanes/alleys narrower, but increased labor cost for herding slow-moving cows will result in a much higher annual cost than would the annualized cost of the initial investment. Cow comfort issues will pay additional dividends.

	Alley Width (ft)	
Alley Location	**Minimum**	**Recommended***
Stalls across from feed manger	13[+]	14[+]
Alley between tail-to-tail stalls	8[++]	10[++]
Feed manger with no stalls on other side of alley	10[+]	12[+]
Alley serving one row of stalls	8	9[+++]
Crossover with waterer (measured from cow side of waterer)	12[++]	15[+]

***** Wider alleys will provide more comfort. Consider a wider alley if equipment must use the alley for manure scraping (tractor, industrial loader, etc.)

[+] McFarland, 2003

[++] Bickert, et al., 2000.

[+++] Graves, 1995

Table 12. Alley widths which allow convenient animal movements

Group Size	Min. Alley Width (ft)
Less than 150 cows	12-16[+]
More than 150 cows	20[+]

[+] McFarland, 2003

Table 13. Minimum alley width for herded cows

Floor Surfaces

Cows must feel comfortable if they are to behave in a natural manner. Good footing is essential to natural walking behavior and to encourage cows to move about the barn and express heat freely. Firm soil, free of stones and mud, is probably the best walking surface for cows, but it is impractical as a walking surface for cows in confinement. Concrete is the traditional surface of choice, but some producers are considering other materials including rubber. Concrete has the advantage of durability but the disadvantage of being hard with no cushioning. Concrete must remain slip-resistant throughout its life yet not be so abrasive that it causes hoof damage. Slip resistance can be provided by: broom finishing, grooving (bull float or cutting), applying aggregates and epoxy coatings, and surface roughening (scabbling). Even sand bedding deposited in the alleys improves traction. Care must be taken to avoid excessive roughness that will wear hooves rapidly. Grooving or broom finishing "green" concrete can leave abrasive surfaces. Plan to drag concrete slabs or use a steel blade with down pressure to smooth these surfaces before allowing cows to use them.

Continued scraping with a steel blade over several years will polish concrete, making it more slippery. When this occurs, use a surface treatment to improve traction. See the article by Gooch (2003a) and *MWPS-7* for recommendations on preparing slip-resistant floors.

Crossover Alleys

Crossover alleys allow animals to move from feeding alley to freestall alley. To allow convenient access, crossover alleys should be spaced at 60- to 80-ft intervals within the freestall row (McFarland, 2003). Crossover alleys are a convenient place to locate waterers, however animals using waterers can interfere with cows that want to crossover. Use the values in Table X to assure adequate width for animal movement. The curb at the rear of the freestall keeps scraped manure from flowing into the stall. Crossovers past which manure is scraped should have a similar step up to a platform. The preferred step up height is 6 inches with no more than 8 inches (McFarland, 2003). Crown the crossover with a maximum slope of 2 to 4% to drain manure, urine and spilled water (Graves, 1995). The step of a crossover can slow animals being herded. If the crossover where cows are herded is at the end of the barn where manure is not accumulating in front of the scraper, consider using no step there. The lack of a step can facilitate the scraping equipment moving between alleys without having to go outside the barn.

Watering

Water is a critical ingredient for producing milk. Cows prefer to drink soon after being milked and during feeding bouts. Producers have observed many cows consuming water when it is provided in lanes used to return from the parlor. Their next stop is usually the feed bunk. Locate waterers in return lanes near the parlor and give cows access to waterers in the housing area closest to the parlor. Since dominant cows can force timid cows away from water, use at least two watering locations within a pen. In larger groups, more than two watering locations can be beneficial to reduce distance between waterers. Consider installing seasonal watering locations to give cows access to water during heat stress periods. Locate waterers away from feed mangers to reduce the amount of feed entering the waterer. A cow requires about 2 feet of waterer length to stand and drink at a trough. Using 1.5 inches of waterer length per cow in a group, each watering space will service 16 cows. An example for sizing the length of waterers needed for a group of 80 cows with three watering locations might look like:

$$\text{Total water trough length (minumum)} = 80 \text{ cows} \times 1.5 \text{ in/cow} \times 1 \text{ ft/12 in} = 10 \text{ ft}$$

Distributing that over three watering locations:

$$\text{Waterer length} = 10 \text{ ft} \div 3 \text{ locations} = 3.3 \text{ ft/location}$$

So waterers longer than 3.3 ft would satisfy the requirement in the housing pen. Waterers in the parlor return should be the number of cows per side times 2 ft/cow.

Cows want clean, odor-free water. Waterers should be set up to be easily and frequently cleaned. Using shallow water depths (4 to 8 inches, McFarland, 2003) and 6- to 12-inch top edge to bottom maximizes the amount of fresh water in the trough and minimizes the amount of water discharged at each cleaning. For large frame cows, place waterers so the top edge is 24 inches (21 to 22 inches for small frame cows) above the floor upon which the front hooves are standing.

Design the water delivery rate to meet the rate of drinking by all cows at the trough. Using a 5 gal/min consumption rate for a cow, the 4-ft troughs in the previous example will require 10 gal/min delivery for two cows using the waterer. Locate a waterproof wall between waterers placed next to freestalls to keep water from being splashed into the stall and to keep cows from reaching for water while standing in the stall. Use a fence around the other three sides of waterers to keep cows from placing their feet in the waterer. Locate the guard rail above the water edge and provide 24 inches clear opening between waterer edge and rail.

Feed Mangers

Design feed mangers to allow cows easy access to high quality feed at all times. Roofs over feed mangers protect the feed from sun and precipitation, each of which can reduce feed quality and increase feed refusal. A roof over the cows protects them from sun, wind and precipitation which can act as deterrents to approaching the feed bunk in certain seasons.

Feed mangers should be flat (no cupping, no front wall) to facilitate easy mechanical clean out and drainage of precipitation. The manger feeding surface should be smooth, of low porosity, and long lasting. A smooth surface will not abrade the cow's tongue. Porous surfaces absorb liquids containing soluble organic compounds. These compounds produce odors upon decomposing. The odors can repulse cows from eating on those surfaces. Suitable surfaces can be provided by troweled high-strength concrete, glazed tile, plastic sheets, and epoxy coatings. It should be noted that high-strength (4500 psi) concrete is not run of the mill concrete. It contains extra cement, less water, and possibly admixtures. Standard concrete will erode quickly in a manger, exposing aggregate and leaving a rough surface. Specify high-strength concrete for a low-cost, long-lasting feed manger surface. A 3-ft wide eating surface provides adequate bunk capacity.

If the drive of a drive-by feed manger is gravel, the manger and the area beyond it should be hard-surfaced to allow feed to be pushed up without pushing up gravel. Make the paved area 5 feet wide as measured from the feed barrier curb (McFarland, 2003). Slope this paved area away from the feed barrier curb at a rate of 1/8 inch per 1 foot to shed precipitation away from the feed.

The feed barrier prevents cows from exiting the pen into the feed manger. Other design criteria include: keeps feed from entering the cow alley, allows cow easy access to feed, allows cow to eat in a grazing-like posture, exerts minimal force on the cow as she reaches, and exposes the cow to smooth (not sharp or abrasive) surfaces. These criteria can be met by using a curb height of no more than 21 inches (1400-lb cows) above the floor upon which the cows' feet rest. The manger surface should be 2 to 6 inches above that same floor. Mangers higher than this have reduced feed storage capacity, reduce the amount of saliva produced by the cow (lowered digestive buffering), and can contribute to feed throwing by the cows.

Feed barriers can include self-locking headgates for animal capture. Self-locks should be designed to allow cows easy access to feed without having to rotate their heads. Look for self-locks which permit quick and safe extraction of a downed cow. The bottom rail of the gang of self- locks should be mounted no more than 21 inches above the floor upon which the cow stands. This will require the curb to be shorter than 21 inches. Consult the stall manufacturer about recommended curb height. Self-locking headgate panels are often installed at a slight angle with the top, tipped away from the plane of the curb. Research has shown that cows put less force on the panel and experience less slipping when reaching for feed with these tipped-away panels. Research at Kansas State University (Brouk et. al. 2001) showed that Dry Matter Intake and Milk Production were not affected by self-locking headgates for cows trained in their use vs a post and rail barrier.

Post and rail feed barriers do not allow animal capture but do provide clear and easy access to feed. The rail is 48 inches above the cow alley floor and 8 to 12 inches in front of the curb as measured from the cow side. The rail should be a smooth round pipe which exerts minimal force and abrasion on the cow if she pushes against it. The location of the rail requires it be spaced away from the support post. Cable is not an acceptable substitute for the rail as it concentrates forces on a small portion of the neck and is abrasive to the hide, each of which cause injury and discomfort.

Bunk space recommendations are based on the management plan and cow behavior. Most cows returning from the milking parlor will approach the bunk to eat before going to lie down. Bunk space must be adequate for animals returning from the parlor to cycle through a trip to the bunk. A more severe test of bunk length is the practice of allowing the bunk to be "cleaned up" for an hour or more before new feed is delivered. Using this practice requires all animals to approach the bunk at once. "Top dressing" with grain causes a similar response. Using self-locking headgates effectively requires sufficient bunk length for all animals in the group to get to the bunk. Use the values in Table 14 when designing bunk lengths based on management.

Management Practice	**Min. Bunk Length/Cow** (in/cow)
All animals must access the bunk at one time (empty bunk refilled, self locks used, top dress grain, etc.)	27*****
Mixed ration always available	18

***** If self-locks will be used, consult manufacturer for specific bunk length per lock-up.

Table 14. Minimum bunk length per cow based on management (Bickert, et al., 2000)

Thermal Comfort

High temperature has more impact on cow comfort than does low temperature. Cows are adapted to cooler climates, eating more to compensate for low temperatures. Practices which minimize the effects of cold stress include delivering extra feed, keeping cows dry (roofs, dry resting area), and offering draft-free spaces (walls, windbreaks). Providing supplemental heat for cow housing is not economical in Wisconsin. During high temperature and humidity conditions, cows reduce feed intake, increase water consumption, seek shade, respire at a faster rate, and will lie in wet areas. Milk production and reproduction efficiency decline as a result of heat stress. The economic impact of heat stress warrants extra investments to reduce such impacts. Practices to alleviate heat stress include: providing adequate quantity and quality of drinking water, providing shade, providing ventilation (removes excess heat and moisture), increasing air velocity past the cow, sprinkling cows to help dissipate heat and lower the air temperature (evaporative cooling, air conditioning), and providing a soft place to lie down.

Ventilation

Ventilation is the process of exchanging contaminated in-the-barn air with good quality outside air. Ventilation is needed continuously throughout the year. The required ventilation rate is lower in winter and higher in summer. Ventilation can be accomplished by natural and mechanical methods. Natural ventilation capitalizes on the forces of nature (thermal buoyancy, wind pressure), while mechanical ventilation uses fans to cause the air exchange.

Natural Ventilation

For natural ventilation to work best, design criteria must maximize the use of the wind. These design criteria include:

Ridge opening*	2 inches per 10 feet of building width
Eave opening (winter)*	1 inch per 10 feet of building width (both eaves)
Roof slope*	4 inches vertical for 12 inches horizontal
Min. sidewall clear opening (ft); both walls in summer	Building width (ft)
9	< 70
11	70 to 95
13	> 95
Separation distance from obstructions located downwind of naturally ventilated building	Separation distance is a function of height and length of the obstruction. For solid walled buildings, a 100-ft separation is a bare minimum.
Terrain	Locate at elevated site, avoid low areas, bluffs, woods, etc.

***** Bickert, et al., 2000.

Mechanical Ventilation

Use mechanical ventilation to cause an air exchange when natural ventilation cannot be used or where ventilation and air velocity and/or air cooling are combined. A mechanical ventilation system should be designed to exchange 50 cubic ft/min (cfm) per 1400-lb cow in winter, 170 cfm/cow in mild weather, and at least 470 cfm/cow in hot weather (Bickert, et al., 2000). The hot weather ventilation rate may not provide enough air velocity to keep cows comfortable, but it should limit building temperature rise to 1 to 3 degrees above outside. Mechanical ventilation can be designed as negative pressure (fans blow out of barn) or positive pressure (fans blow into barn). Common negative pressure systems are: fans in walls with slot or area inlets, and wind tunnel (fans on one end and inlet at other end). Common positive pressure systems are: positive pressure wind tunnels (fans blow in one end and air outlets at other end), ducted systems (fans force air into barn though ducts), and distributed fan systems (fans located in walls or ceiling around the barn). A combination of both negative and positive pressure systems may also be installed. Wind tunnel systems combine ventilation and air velocity to help keep cows cooled. Effective wind tunnel designs for freestall barns use an air velocity of 500 to 600 ft/min. This requires limiting the barn cross-section through which air flows by means of using a ceiling or vertical baffles suspended in the vaulted space above the eave at a maximum spacing of 50 feet (Gooch, 2003b). One limitation of wind tunnels is the impact on air movement downstream of obstructions. Obstructions include: waterers and walls behind them, stall curbs, stall dividers and fences, and, most importantly, the cows themselves. Some producers will bleed air into the barn through narrow openings at the bottom of the wall curtain to introduce fresh air with velocity to cows lying in stalls along the wall.

Cow Cooling

Cows benefit from moving air past their body surfaces at 3 to 6 mph of velocity. However, when temperatures approach or exceed 100°F, air velocity has limited effect. Sprinkling cows with water to wet them to the hide allows their body heat to evaporate the water, providing surface cooling. Combining the effect of sprinkling and high air velocity past the body surface maximizes the cooling benefit. In winter this process is known as "wind chill". Researchers at Kansas State University (Brouk et. al., 2003) have shown the benefits of reducing heat stress by reducing the wetting cycle time. They currently recommend cycle controllers that reduce the sprinkling cycle time as temperature increases (Table 15). Sprinkler nozzles are usually mounted to spray cows' backs as they stand at the feed manger, in the holding area, and in the parlor return lane. See some of the Recommended Readings for useful design information.

Temperature Range (°F)	**Soaking Frequency** (min)
70-80	15
81-90	10
> 90	5

Table 15. Recommended soaking frequency based on ambient temperature

Circulating fans are located to blow air onto the cows standing in the feed alley, lying in freestalls, and standing in the holding area and in the parlor. Circulating fans have the most effect when they are spaced at no more than 30-ft intervals for 36-inch diameter fans and at less than or equal to 40-ft intervals when they are greater than 48 inches in diameter. The fans should be aimed downward so the projection of the fan axis impacts the floor directly under the next fan in a series. Circulating fans have the most benefit when they blow air parallel to a cow's body length as in the holding area. The effectiveness is reduced when upstream cows block the air flow as in the feed line and cow stalls. Consider a system of fans that blows air parallel to a cow's body in freestall housing areas.

Locate 150- to 180-degree sprinkler nozzles over cows standing at the manger and 360-degree nozzles in the holding area and return lanes. Space nozzles so the spray pattern overlaps to get good coverage. A nozzle spacing of 6 to 8 feet can work well at the manger and in the holding area. Select nozzles capable of delivering 0.03 gal/ft^2 and 0.3 gal/min at 10 psi of line pressure. Plan to deliver 0.08 gal/cow to achieve adequate wetting. If a timer is used to reduce the on-off cycle time to 5 minutes, the sprinklers must have the capacity to wet the cows in about one minute. This requires the system to deliver 0.3 gal/min/sprinkler. High-capacity sprinkling systems require the delivery system be sized adequately. Piping should be large enough to avoid high friction losses, and water well delivery and pumping capacity should be large enough. For example, a 100-cow group at the feed manger receiving 0.08 gal/cow/min requires a delivery rate of 8 gal/min. Most nozzles allow the delivery line to drain down during off cycles. This drain down water enters the manure and manure storage, increasing the cost of manure transport. Installing delivery lines perfectly level and installing sprinklers on the top of the line or using valved nozzles on sloping lines can conserve water and avoid having to handle a greater volume of manure. The extra cost of these systems can pay for themselves quickly by reducing the cost of manure hauling and increased manure storage capacity.

Evaporative Cooling

Warm, dry air can be cooled by using it to evaporate water. This principle is used with misting and evaporative cooling pads. The air temperature decline is a function of air relative humidity and the quantity of water added to that air. These systems can work best when the relative humidity remains low throughout the day (Brouk et. al., 2003). In humid climates like Wisconsin, the relative humidity drops during the day and increases at night. Thus an evaporative cooling system works best only during the day. The effect of evaporative cooling may be limited by the rate at which water can be evaporated into the air. Large evaporative pads and fine water droplet mists are required to maximize water evaporation. Consult equipment manufacturers for proper system designs.

Evaporative cooling technologies may allow for lower ventilation rates in summer due to reduced heat stress. However, care must be taken to limit the maximum relative humidity in the barn. Animals still need to evaporate water from their bodies to cool themselves. High humidity also supports aerosol-borne pathogens which can increase disease incidence. High humidity makes it more difficult to keep stall surfaces dry. Avoid misting over the stalls to avoid condensation and spray precipitating onto the stall surfaces. Evaporative cooling pads can be conveniently incorporated into wind tunnel ventilated freestall and tie stall barns.

Recommended Reading

MidWest Plan Service (MWPS), publications available. Phone: 515-294-4337; Web: http://www.mwpshq.org.

Natural Resource, Agriculture, and Engineering Service (NRAES), publications available. Phone: 607-255-7654; Web: http://www.nraes.org

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