Designing Welfare-friendly Housing for Dairy Cows

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Abstract

This article attempts to use our available knowledge of how environmental factors impact the dairy cow to create biological thresholds for housing design, which enable her to have adequate time for eating, drinking, socializing and rest. Thresholds for herd and group size, stocking density, pen layout, stall design, ventilation and cooling are discussed to describe a facility for 1,400 dairy cows, housed in groups of 150 cows, milked three times a day through a double 20 parlor in a freestall barn with two-row pens, with stalls sized to accommodate the type of cow using them, with sand bedding, and adequate cooling and access to water and feed.

Résumé

Cet article tente d'utiliser nos connaissance actuelles sur l'impact des facteurs environnementaux sur les vaches laitières afin de créer des limites biologiques pour la conception des stabulations qui permettraient aux vaches d'avoir assez de temps pour manger, boire, socialiser et se reposer. Les limites pour la taille du troupeau et du groupe, pour la densité des animaux, la répartition des enclos, la conception des stalles, la ventilation et le refroidissement sont discutées dans le cadre d'un établissement de 1400 vaches laitières en groupes de 150 vaches traites trois fois par jour dans une salle de traite double de 20 dans un étable à stabulation libre avec des logettes sur deux rangées. Les logettes ont une taille qui permet d'accommoder les différents types de vaches qui les utilisent et ont une litière de sable, un refroidissement adéquat et l'accès à la nourriture et à l'eau.

Introduction

As soon as we choose to house cattle rather than manage them at pasture, we are making a conscious decision to modify their behavior. Although the pastoral image of cows grazing lush green pastures promotes an ideal image for the dairy industry, often used and misused by the industry to market its product, there are very good reasons for housing cattle. Heat stress from lack of shade, hunger due to lack of sufficient grazing, exposure to driving rain, snow and freezing cold weather and control of parasitism are all excellent reasons to develop a housing environment where we are better able to shelter the cow. Dairy cow housing may take the form of a tiestall, freestall, or a bedded pack. In this article, I will focus on the freestall, which has emerged as the dominant housing system in many different climates around the world.

Dairy cows housed in a freestall barn, fed a total mixed ration (TMR) and milked in a parlor two-to-three times a day are clearly not living a life their ancestors were designed for. It is also clear that whatever housing design we choose, the cow is compromised to a greater or lesser degree. That said, I believe it is important to find biological thresholds for design features above which the cost to the animal in terms of ill-health or effects on physical or mental well-being are too great, and below which we can create an affordable, welfare friendly environment in which cows can thrive and live in harmony with their caregivers.

Until recently, the design, dimensions and materials used for housing dairy cows has had more to do with engineering standards than with biological standards. Stalls, roofs and flooring have been constructed with a focus on durability rather than cow longevity. There is a good reason for this - herd owners certainly do not want to build a structure at considerable expense that will last only a few years. However, it is clear from recent observations on the impact of the environment on cow ergonomics [1] and health and well-being [2] that a new set of standards are required that optimize the relationship between biological fitness of the cow and the durability and cost of the environment.

Time Budgets

The dairy cow is a workaholic. She spends much of her life operating at three times the energy cost of maintenance – something humans only approach while performing strenuous physical activities on a par with jogging six or more hours a day or competing in the Tour de France – and the dairy cow accomplishes this for a lifetime.[20] So, if our cows make Lance Armstrong look like a 'couch potato', it seems reasonable to examine her daily requirement for food and rest, so that we can make sure we are providing for her needs.

From an analysis of 250 total 24-hour time budgets we have collected from 208 cows housed in 17 freestall barns in Wisconsin, the average time spent performing each of five key behaviors is shown in Table 1.

Certain components of the cow's day are fixed and non-negotiable. The cow has to spend a large proportion of the day eating to fuel the large fermentation vat that

Table 1. The mean (range) 24-hour time budgets for 208 cows filmed over 250 filming periods in 17 freestall barns in Wisconsin.

N=250	Mean	Range
Parity	2.7	1-10
Milk Yield (lb per day)	91	24-160
DIM	158	7-541
Mean Locomotion Score (1-4)	1.7	1-3
Time lying down in the stall (h/d)	11.3	2.8-17.6
Time standing in the stall (h/d)	2.9	0.3-13.0
Time standing in the alley (h/d)	2.4	0.2-9.4
Time drinking (h/d)	0.4	0-2.0
Time feeding (h/d)	4.4	1.4-8.1
Time milking (h/d)	2.6	0.9-5.7

she has to carry around with her. The TMR-fed, freestall-housed dairy cow eats for an average of 4.4 hours per day (range 1.4-8.1). Note that this is about half the time that a grazing cow spends eating per day – pasture cows average around 8-9 hours per day eating. She also needs to drink around 25 gallons of water per day (more in hot climates) and she will spend an average of 0.4 hours per day at or around a waterer. Milking time is usually spent outside the resting area in all but tiestall herds, and in 17 Wisconsin herds milking two-to-three times a day, the average cow spent 2.6 hours out of the pen milking, with a wide range from 0.9-5.7 hours per day. With these fixed non-negotiable time slots, we have already taken 4.4 + 0.4 + 2.6 = 7.4 hours out of the time budget, leaving under 17 hours remaining in the pen.

Time left in the pen will be spent performing three activities – lying down, standing in an alley and standing in a stall. The average freestall cow spends 2.4 hours per day standing in an alley socializing, moving between the feed bunk and stalls and returning from the parlor. Once in the stall, the average cow spends 2.9 hours per day standing in the stall (range 0.3-13.0) and 11.3 hours lying in the stall (range 2.8-17.6) – but note the wide ranges in these behaviors. Lying behavior is typically divided into an average of 7.2 visits to a stall each day (called a lying session), and each session is categorized by periods standing and lying – called bouts. The average cow has 13.6 lying bouts per day and the average duration of each bout is 1.2 hours (range 0.3-2.9). Most cows will stand after a lying bout, defecate or urinate, and lie back down again on the contralateral side. From studies designed to make cattle work for access to a place to rest, it would appear that cows target around 12 hours per day target lying time,[10,13] and this is in agreement with the lying times found in well designed freestall facilities.[3] It should be noted that this exceeds the reported lying times of cows at pasture of 8-11.5 hours per day.[15,17]

Determining Maximum Group and Herd Size

No aspect of dairying creates more concern to the general public than herd size. The perception of 'factory farm' dairy cows is an emotive subject, so it is interesting to look at herd and group size from the perspective of the cow. While there are economies of scale for the herd owner as herds get bigger, how big is too big for the cow? I believe the limitations to herd size from the perspective of the cow focus on three main areas:

1. Milking time and time away from the pen
2. Walking distance from the parlor
3. Our ability to detect a sick fresh cow in a pen of other fresh cows

Milking time and time away from the pen

If we use 12 hours per day as the 'required time for lying' as our starting point, and re-examine the time budget by subtracting time feeding and drinking in addition to what we view as 'normal' times standing in the alley and time standing in the stall, we find that the time available for milking is 24 – (12 + 4.4 + 0.4 + 2.4 + 2) = 2.8 hours per day. From a facility design perspective, this means that dairies that wish to milk three times a day must limit time out of the pen to 56 minutes each milking. If cows walk at around three feet per second at best, factoring in other delays, total travel time to and from the milking center would be a minimum of five minutes or so, leaving around 50 minutes for milking.

The most efficient parlors currently achieve a rate of milking that approaches 4.5 turns per hour (one turn being the time taken to fill and empty a row of milking stalls), and obviously the longer the row of stalls, the greater the throughput in terms of cows milked per hour. Each turn takes 13.3 minutes to milk at 4.5 per hour, so the actual number of turns milked in 50 minutes (our maximum allowable milking duration for all of the cows in a pen) would be 3.8. The maximum group sizes therefore range from around 60 cows up to 228 cows across the range of parlor sizes typically constructed in North America.

Assuming that the parlor runs for 21 hours per day at 4.5 turns per hour, a total of 94 turns are milked per day. The maximum milking herd size therefore ranges from 500 to around 1,880 cows for herds milking three times a day, and up to 2,820 cows for twice a day milking, based on one biological threshold – time out of the pen milking.

Walking distance from the parlor

In our current estimate, we are allowing five minutes for transfer time to and from the parlor back to the pen. An example dairy with 5,000 milking cows and a group size of 208 cows would have 24 milking pens. Typically, we build facilities with four pens per barn, one in

Table 2. Target group and herd size based on minimizing time out of the pen milking to 2.8 hours per day.

Parlor size	Double 8	Double 12	Double 16	Double 20	Double 30
Maximum group size = cows milked in 3.8 turns	61	91	122	152	228
Maximum size of milking herd (assuming parlor operates 21 h/d and cows milked 3 times a day)	501	752	1003	1253	1880
Maximum size of milking herd (assuming parlor operates 21 h/d and cows milked 2 times a day)	752	1128	1504	1880	2820

each quadrant, with the pens emptying in the middle, so this facility would have six barns, each at least 100 feet wide, spaced with a gap between buildings of 1.5 building widths, or 150 feet. Now we have a situation where many cows must walk 800 feet per milking, or 0.45 miles a day, to and from the milking center. It is not surprising therefore to see the emergence of thin soles and associated lameness as a result of this increased requirement for traffic on hard-wearing surfaces.[16]

While it is possible to reduce wear rates with the use of rubber walking surfaces,[19] others have reported that excessive walking is a stress in itself, affecting production and udder health,[6] and VanBaale *et al* failed to identify an increase in milk production in a frequently milked fresh cow group in a large commercial dairy in Arizona, citing transfer time and distance from the parlor (285 feet) as a potential reason.[18]

We do not know how far is "too far" for cows to walk without it having an adverse effect on health and production. From experience, horn wear rates appear to become an issue in herds where cows must walk greater than one barn distance from the parlor. If we put a limit on this walking distance – of about 300 feet per milking, the facility would have a maximum of eight pens of around 200 cows each, or a herd of 1,600 milking cows. If we tolerated walking cows from a second barn 400 feet from the milking center, and added rubber flooring to reduce hoof wear, herd size could go to a maximum of 3,200 milking cows.

Our ability to detect a sick fresh cow in a pen of other fresh cows

In large dairy herds, in order to monitor sick cows, we typically group the high-risk animals in a single fresh cow group for a period of 14-21 days after calving, so that they can be monitored closely. So, what is an acceptable time period to have cows locked up, while this check takes place?

Let us return to the time budget, and now start with milking time at 2.8 hours per day. Time left in the pen after resting for 12 hours and standing in the stall for 2.9 hours is 6.3 hours per day. Time spent in lock up must compete with time standing in the alley, time feeding and time drinking. Cows may also eat while they are locked up at the feed bunk, but peak feeding activity after delivery of fresh TMR typically lasts no longer than 45 to 90 minutes before cows lie down and rest.[12] Locking cows up at fresh feed delivery for more than about one hour per day would therefore mean that time available in the alley would be reduced, and it is feasible that cows would make this choice. However, it is likely that lock up time exceeding two hours per day cannot be compensated for, as it is unlikely that a cow will willfully spend zero hours standing in the alley. Indeed, although the lock up time employed by Cooper *et al* did not coincide with at least some feeding time, they did show that when cows were deprived of lying for two to four hours per day, they only managed to recover approximately 40% of the lost lying time by 40 hours after the deprivation.[5] These findings point to a maximum allowable lock up time of around two hours, assuming that at least one hour of this coincides with fresh feed delivery, if we are not to erode the time available to the cow for rest.

At a minimum time period of one minute per cow to check if she is eating, has adequate rumen fill, normal feces and udder fill, the maximum fresh cow pen size would be 120 cows, which for a 21-day pen stay duration, would be a herd size of 2,000 cows, without taking into consideration the surges in calving rate that occur from time to time.

How big is too big?

In answer to the question – 'How large can herds be so that we do not compromise the health and well-being of the dairy cow?' the upper limit we are arriving at from limitations placed on the cow's time budget, is around 3,000 cows. If we make herds larger than this threshold – perhaps because we choose to milk cows faster with a 72-cow rotary parlor, the amount of walking cows must do and our ability to detect sick cows become the limiting factors. On the other hand, if technologies develop that enable us to triage fresh cows for illness more quickly and effectively, then parlor throughput may become a limiting factor.

However, the assumptions mentioned above were largely best-case scenarios, with parlors working at peak efficiency, and experienced workers working rapidly all of the time. This doesn't happen very often on the dairy farms I visit around the world, so it is perhaps wise to build in some flexibility. For that reason, I currently view the 1,400-cow dairy, milking approximately 1,200 cows through a double 20 parlor three times a day, with group sizes around 140-160 cows as representative of the upper limit for the 'optimal' herd at this time. There are undoubtedly elite dairymen that achieve astonishing results in larger herds. However, when creating a blueprint for an industry it is wise not to base our assumptions on the fact that all dairymen will be elite managers.

Impact of Overstocking

Overstocking is another emotive issue, and one that appears on many welfare audits for dairy cows. However, there is much confusion over the definition of overstocking and its interpretation. For example, in parts of Europe they legislate that there must be one available stall per cow, and yet in a three-row pen stocked at one cow per stall, bunk space availability may be far less than in an overstocked two-row pen. So, we need to be clear about what it is we are overstocking – the stalls or the bunk, for these are two quite separate issues. In simple terms, lack of stall space is a lying-time issue which impacts foot health primarily, while lack of bunk space impacts food intake, making it a metabolic issue.

Overstocking the Stalls

Studies monitoring overstocking in small groups of cows under tightly controlled situations suggest that overstocking does decrease lying time.[7,8] However, for lying times to drop below the target of 12 hours per day, most of these studies find that stocking rates in excess of around 1.2 cows per stall are required, and much greater overstocking is required to see impact on milk yield and health indicators such as lameness.[8,11] This observation makes sense because each cow is attempting to find 12 hours of stall occupancy per day during a pen stay duration that is usually around 21 hours per day – so this allows for a degree of time and space sharing to occur. Of course, these studies fail to recreate the challenges faced by dairy cows on commercial herds each and every day – pen moves, social changes, time spent in lockup, and delays in feed delivery, all of which influence the time budget for each cow. I would argue that for transition cows we need to supply one usable stall per cow, while cows with fewer daily stresses, such as pregnant or late-lactation cows, may tolerate overstocking up to around 1.2 cows per stall.

There is also the issue of what constitutes a 'usable stall'. Just because we build and provide a stall for a cow, it does not mean that all stalls are treated equally and used identical to one another. The 'effective stall stocking density' may be quite different. With small, 45-inch-wide stalls, it is common for the rumen and legs of one cow to overlap adjacent stalls, potentially reducing the use of these stalls. For that reason, stalls should be sized appropriately to the size of the cows occupying them.

Overstocking the Feed Bunk

Feed bunk use contrasts with how stalls are used by dairy cows. There are very few periods of peak bunk use activity throughout the day – timed to coincide with return to the pen from milking and when fresh feed is delivered – and these periods are of relatively short duration, on the order of 45-90 minutes.[12] We now know that when all the cows fail to eat at the same time during these peaks in activity, subordinate cows do not go back to the bunk to eat later.[9]

A reduction in dry matter intake (DMI) in transition cows will manifest in increased rates of metabolic disease, such as ketosis, metritis and displaced abomasum, and reduced milk production. Oetzel *et al* showed that the impact of over-stocking in a pre-fresh group housed in a two-row pen on a 1,600-cow facility was greater for first-lactation animals penned with mature cows. There was a 6.5 lb-per-day (2.9 kg) decrease in milk production over the first 85 days of lactation in first-lactation animals stocked at 120% with respect to stalls, compared to overstocking at 80%.[14]

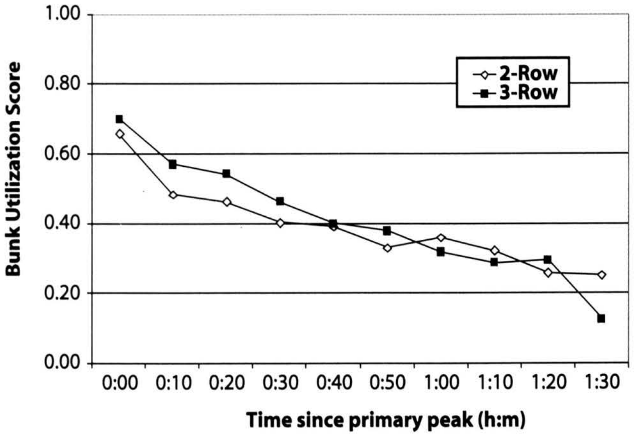

Figure 1. Graph of bunk utilization score (proportion of feed spaces filled) through the period 90 minutes after fresh feed delivery (primary peak) in two-row and three-row barns. Headlocks were spaced at 24 inches on center (from Mentink and Cook, 2006).[12]

Note from Figure 1 that cows do not voluntarily fill 24-inch-wide headlocks beyond around 80% fill – which equates to a bunk allowance of around 30 inches per cow. So, we recommend that transition cows, with lower DMI, are provided 30 inches of bunk space per cow and that the feed spaces are defined by head locks to reduce competition at the feed bunk between cows.[9] For cows beyond the transition period, I have no evidence to ask for more than 24 inches per cow at this time.

Pen Design and Layout

Once we understand how overstocking influences cow behavior, we can understand that the concept of a three-row pen is inherently flawed. The behavior of the cow dictates that she will tolerate fewer stalls being available easier than less bunk space. If we overstock a three-row pen, we go against the coping mechanisms of the cow. Cows may tolerate overstocking much better in two-row pens – where for cows beyond the transition period, we can optimize stall occupancy by having slightly more cows per stall (up to a threshold of 1.2 cows per stall), while still maintaining bunk space access above a minimum allowance of 24 inches per cow.

The options for layout of two-row pens include head-to-head, tail-to-tail and head-to-tail orientations of stalls. From the cow's perspective there are no major differences between these options, provided that the stalls are appropriately sized with ample lunge space.

The issue of how far a cow should have to walk between crossovers between the feed alley and the stall alley is open for debate. One can argue that the distance should be less in pen layouts with no direct stall access from the feed alley (ie. tail-to-tail layouts), but distances of 80-100 feet (or 20-25 stall widths) are currently suggested in most lactating cow pens. In transition cow pens, more frequent crossovers every 12-15 stall widths are recommended to improve bunk availability. As waterers are usually located in crossovers, water access must also be taken into account when determining the optimum number of crossovers. The current recommendation is to provide at least 3.5 inches of accessible trough perimeter per cow and at least two locations per pen.

The width of the alley depends on its purpose. For the feed alley where a cow must stand at the bunk eating, or a crossover where cows must stand and drink at a waterer, we suggest that there be sufficient space for two cows to pass behind the cow side-by-side. If cows are approximately three feet wide and six feet from brisket to tail, then the minimum alley width is 6 + 3*2 = 12 feet. For a feed alley with stall access (head-to-head or head-to-tail layout) we add two additional feet, and for a stall alley, with no feed or water access, a minimum of 10 feet is recommended.

Stall Design

Stalls must be designed to meet the requirement of each cow to obtain at least 12 hours per day of rest. We have found that the main factor determining whether a cow spends time standing or lying down in the stall is lameness, and surface cushion and traction are the key determinants of success of a stall surface. When cows with sore feet have to rise or lie down on a firm, unyielding surface, such as a mat or a poorly cushioned mattress, the pain associated with the process leads to increased time spent standing in the stall between lying bouts, fewer lying sessions per day and a decrease in lying time.[3] Sand, because of its ability to supply traction and support to the weight-bearing limb during rising and lying movements, is an optimal surface for both non-lame and lame cows alike and results in short stall standing times, typically less than two hours per day. It remains to be seen whether other deep loose bedding materials such as chopped straw, sawdust or composted manure solids behave in the same way, but it seems logical to expect that these materials would be more similar to deep sand than to a firm mat or mattress. However, until proof is obtained, sand remains the gold standard for stall base, with less risk for udder health issues than the other materials.

Other aspects of stall design that are essential to cow use are:

- adequate resting area, defined in front by a brisket locator that does not impede the forward thrust of the forelimb during the rising motion, and allows the front legs to be outstretched when the cow is resting, and defined laterally by dividers located wide enough to reduce disturbances from neighbors, and modeled so as to allow the normal lying positions of the cow;
- adequate room to lunge the head forward, or to the side, so the cow can perform the normal sequence of movements for rising and lying, without modification of weight bearing between the front- and hindquarters;
- room to rise below and behind the neck rail without risk of injury or entrapment;
- a rear curb high enough to prevent manure contamination of the stall during cleaning of the alley, but low enough to facilitate easy departure from the stall, especially for lame cows.

From the perspective of creating a stall as attractive and functional for a lame cow as it is for a non-lame cow, sand bedding is the ideal surface. The remainder of the design depends on the size of the cow occupying the stall, and appropriate target dimensions are given in Table 3.

Table 3. Target freestall dimensions based on an estimate of body weight.

Stall dimension (inches)	Body weight estimate (lb)				
	1000	1200	1400	1600	1800
Stall length	96	96	108	120	120
Distance from rear curb to brisket locator	64	66	68	70	72
Stall width	44	46	48	50	54
Height of brisket locator above stall surface			4		
Height of upper edge of bottom divider rail above stall surface			12		
Height below neck rail	44	46	48	50	52
Horizontal distance between rear edge of neck rail and rear curb (subtract width of curb for sand stalls)	64	66	68	70	72
Interior diameter of loop	30	32	34	35	36
Rear curb height			8		
Rear curb width (loose-bedded stalls)			6		

Ventilation and Cooling

Thermal comfort and good air quality are very important for the health and well-being of the dairy cow. In general, the dairy cow is far more tolerant of cold than she is of heat stress. When cows are hot, they stand in an attempt to increase heat loss and freestall cows under conditions of mild to moderate heat stress stand for an additional three hours per day[4] at the expense of lying time. Cows begin to modify their behavior at around a thermal heat index (THI) of 68 – generally before we begin to feel hot.

In a recent survey of 29 freestall barns in the midwest and California (Schefers; Personal Communication), we found the most important factors for cooling the cow and lowering humidity in the barn were:

1. Orienting naturally ventilated barns from east to west rather than north to south.
2. Controlling stocking density.
3. Providing sufficient fan capacity in the holding area. Current recommendation is for at least 1,000 cubic feet per minute (CFM) per cow.
4. Reducing time spent in the holding area and the parlor.
5. Providing fans over the resting area.

These five points are critical for heat abatement and good results can be achieved in naturally ventilated barns, located so as to capture prevailing winds in the summer. Soaker systems can be added to the holding area most importantly, and in the pens secondarily to further assist cooling. Barns may also be ventilated mechanically with either tunnel or cross ventilation, and these provide an option for housing where natural ventilation is not viable.

Conclusions

With our current knowledge of the behavioral needs of the cow, in order to ensure her health and well-being, we are able to design a housing facility that is not only economically viable for the herd owner, but in many ways improves on life on pasture, providing greater comfort, longer resting times, less lameness and greater protection from the elements.

We are conditioned to enjoy the sight of dairy cows grazing or lying down together on lush green pasture, and certain welfare organizations demand that we make grazing a requirement for all dairy cows. This would not be a bad idea if we hadn't spent years genetically selecting for the type of cow we currently have, and we could control the weather. Unfortunately that is not reality, and we should not impose unsubstantiated management requirements on our farms when we have no idea what impact that might have on cow well-being. Rather, we should quantify the needs of the cow and identify biological thresholds to optimize our production systems to promote production, health, well-being and longevity in the dairy cow. Without a doubt, many of our cow barns are to be found wanting in many areas. However, there are a growing number of progressive producers that realize the benefits of remodeling facilities to improve cow comfort, and they are leading the way.

There is evidence to suggest that herd size may be getting to the point where cow well-being is being compromised. However, not all dairy herds above 60 cows are 'factory farms', and in this article I have described welfare-friendly housing for a 1,400-cow dairy. As veterinarians, we must make the consumer aware that farms of this nature are the future of our dairy industry and we are working hard to ensure the well-being of the animals under our care. At the same time, we must educate dairy producers on aspects of barn design that are having a negative impact on the health of the cow. Let us not forget that we are, and will continue to be, the primary advocates for cow well-being on the farm.

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