

Behavioral needs of the transition cow and considerations for special needs facility design

Nigel B. Cook, BVSc, MRCVS*,
Kenneth V. Nordlund, DVM

*Department of Medical Sciences, Food Animal Production Medicine, School of Veterinary
Medicine, University of Wisconsin, 2015 Linden Drive, Madison, WI 53706, USA*

The purpose of this article is not to provide an all-encompassing guide to the building of a new dairy facility, as other sources can provide much more detailed information on engineering matters related to flooring, roof designs, insulation requirements, barn location, and manure handling. Rather, we take this opportunity to discuss matters of building design that immediately impact the health and welfare of the transition cow, areas that fall within the domain of the veterinarian. During the planning and management of transition cow facilities, we believe that it is the responsibility of the veterinarian to serve as the advocate for the needs of the dairy cow.

Central to any discussion of housing requirements for dairy cows is an understanding of their social behavior. Before examining specific facility requirements in detail, we will therefore start by considering the behavioral stresses encountered by dairy cows in modern free-stall barns, the challenge of pen moves to different management groups, and the effects of overstocking within these groups.

Behavioral needs of the individual cow

Much research has examined the effect of different environments on milk production and dry matter intake (DMI) of small groups of cattle over relatively short periods of time. It is our view that many of these studies have inadequately demonstrated the true impact of environmental factors on cow health by failing to monitor low rank subgroups of the population. In simple

* Corresponding author.

E-mail address: nbcook@wisc.edu (N.B. Cook).

terms, compromised environments do not affect all animals equally. Ill health does not affect all of the individuals in a pen at the same time; rather, some cows are unaffected and perform well, while a few succumb to disease and perform poorly. Monitors based upon group mean DMI and milk production are likely to miss the adverse effects on outlier cows that are unable to compensate in a compromised environment. We believe that to improve the health and well-being of dairy cattle in modern free stall facilities, we must provide for the needs of each cow so that she can behave as a herding animal, eating with the herd, resting with the herd, and socializing without fear.

Grouping cows

The replacement of old tie-stall barns with free-stall housing has brought with it a change in the life style of the dairy cow. Traditionally, the tie-stall cow was milked in the stall, fed in the stall, drank water from a cup in the stall, and stood and lay down in the stall as she required. In most situations, cows were allowed outside of the barn for 2 to 4 hours per day for exercise and to display signs of heat. Her production level and ration might change, her pregnancy status would change, and she might receive treatment for injury or disease, but she would remain in the same stall with her herd mates in place on each side. In essence, management was brought to the cow in her tie-stall.

In contrast, the cow in the large free-stall barn moves to management groups. She is moved to different pens for special rations, breeding, dry off, treatment, and other management practices. Smith et al [1] have described the use of the groupings, outlined in Fig. 1 under the “Traditional” column, for the management of transition cows. From the far-off dry-cow group, a cow is typically transferred to the close-up dry-cow group at 14 to 21 days before the expected calving date. From here, she is often moved to a bedded pack maternity pen at around 3 days before the expected calving. After calving, she is moved to a pen for cows with nonsaleable milk to stay for 2 days, then to a fresh-cow pen for 14 days, and then to a high-group pen. This plan completes five pen moves in a period of less than 5 weeks. Essentially, the cow moves to management and finds herself in a different space, surrounded by different herd mates, and subject to the management change for which she was moved. As investigators of problem herds, we have become increasingly concerned about the frequency and character of these pen moves on the well-being of the transition cow.

Pen moves

Effect of pen move on the group mean

Moving cattle between groups brings about a period of increased social interactions, many agonistic, before stabilization and development of a social

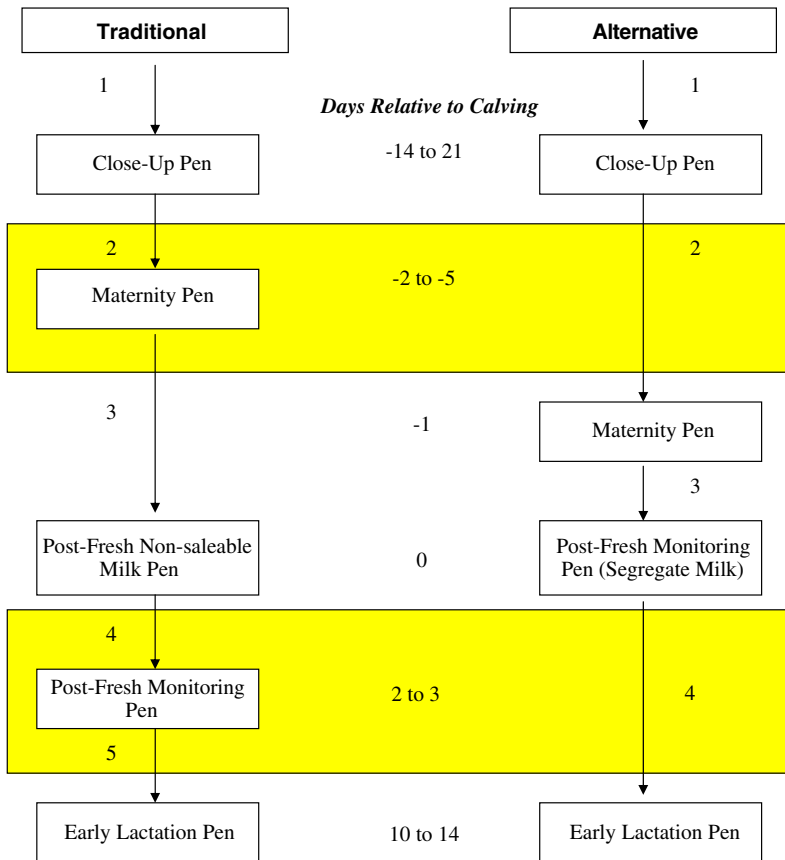


Fig. 1. A pen move comparison for the traditional grouping strategy for transition cows, compared with an alternative strategy aimed at avoiding moves between 2 and 5 days before calving and 2 to 3 days after calving (highlighted in the shaded areas).

hierarchy [2]. For lactating cows, Grant and Albright [3] report that social impacts of moves last around 3 days and almost always less than 7 days. Kondo and Hurnik [2] conducted a study on the behavior of lactating dairy cows after pen changes where two groups of 16 lactating dairy cows each were assembled in free-stall pens and monitored for 5 weeks, after which half of each group were randomly selected and reassembled into a third group. Agonistic interactions between cows were characterized as physical, which included bunting, pushing, and fighting, or nonphysical interactions that included threatening and avoidance behaviors. The frequency of agonistic interactions was high for the first 48 hours after grouping, averaging over 300 events per 2-hour recording session. After 48 hours, the frequency had stabilized at about 100 events per session. During the first 48 hours, approximately 65% of interactions were physical and 35% nonphysical.

After the second day, this ratio had reversed to around 40% physical and 60% nonphysical. When cows are moved into stable groups, the moved cows are involved in more agonistic interactions than the stable cows. Brakel and Leis [4] showed that during the first day after regrouping, the average moved cow was involved in 9.6 interactions per hour, approximately double the rate of the other cows in the pen. Obviously this increase in physical interactions during the first 48 hours of joining a new group may have an effect on other behaviors performed during the day—feeding and resting time in particular, which may in turn, influence milk production.

Research on the milk production effect of pen moves on the average cow in the group has found mixed results. Generally, a pen move has a negative effect on milk yield of the transferred cows of the order of 2% to 5% for a short period [4–6], but not in all situations [7,8]. For example, Brakel and Leis [4] found a 3% decrease in fat corrected milk yield of the transferred cows on day 1 of the move. It should be noted that many of these studies were conducted with mature cows in mid-lactation and not with cows in the transition period.

Studies on the effect of the number of cows moved at one time have generally found that movement of single animals should be avoided, as it is believed that familiarity and social bonds between three to five moved animals may reduce the social stress of integrating within a larger group [9]. Sowerby and Polan [5] did not find significant production differences between groups where between 2% and 14% of the cows were transferred at one time. Studies on the effect of the size of groups moved into large pens of 100 to 300 cows have not been reported.

Effect of pen move on individual cows

Although the effect of pen moves on the average cow appears to be modest, the effect appears to be more significant on low-rank cows. The subject of rank and social dominance is complex. Lamb [10] describes three different ranking orders in cow herds, dominance, leadership, and parlor entrance order, and reports that the rankings for each are not the same. For example, the “leader” cow is not likely to be the most dominant cow. Dickson [11] reported that cows form dominance hierarchies strongly associated with age, body size, and seniority in herd. Changing conditions for individual cows such as weight gain or loss result in rank changes. Arave [12] reports a trial of individually fed primiparous cows, some receiving a ration that exceeded energy requirements and others receiving an energy-deficient diet. Rank within the group changed continually as some cows gained weight, strength, and social dominance, while cows on the low energy diet lost weight, strength, and rank. Pen moves are also responsible for changes in rank. Dominance relationships between pairs of cows are gradually learned, but once formed, they tend to last for a long time [13]. Cattle moved to a new pen will tend to maintain their rank relative to the cows that were moved [14],

but occupy a low rank with respect to the other cows, even first lactation, that already occupy the pen. However, the situation may become more complex. Hook [15] observed a complete reversal of the social rank of a group of six heifers with the removal of the high-rank individual and the simultaneous introduction of a new heifer.

Primiparous cows are usually subordinate to multiparous cows. Phillips and Rind [16] studied behavior and milk production of mixed and unmixed parity groups on pasture after assembly of the groups. Unmixed groups of either primiparous cows or multiparous cows produced 3% more milk in the first week than equivalent cows in the mixed group. Both primiparous and multiparous cows spent more time standing and less time grazing in the mixed group. The primiparous cows spent more time grooming, a submissive action, while the multiparous cows increased pasture biting rates, an aggressive action, compared with their contemporaries in unmixed groups.

Hasegawa et al [6] described the effect of pen moves on dominant, middle-rank, and subordinate primiparous cows. Dominant animals showed little change in behavior and production, but middle-rank and subordinate cows produced 3.8% and 5.5% less milk in the second week after movement to a new pen. Subordinate individuals spent more time eating than dominant cows, spent more time standing—especially on day 2 after the move, and had a greater frequency of short lying bouts of less than 15 minutes in duration, suggestive of disrupted lying behavior.

Robinson et al [17] found no difference in subsequent early lactation milk production following exposure to either 11.7% or 14.4% crude protein prefresh rations. However, the time for which primiparous cows had access to the diets was significant. Close-up primiparous cows that spent 9 or more days on the control ration produced significantly more milk in the subsequent lactation than those that spent 8 or fewer days on either ration. In contrast, there were no significant differences in response of multiparous cows to either ration or duration of exposure. This finding indicates that exposure to the social turmoil that occurs within a short stay-high throughput group, where animals are removed and new animals are added daily, may have a greater effect on primiparous cows. It is possible that longer duration stays allow some individuals to become elevated in rank, while those that only remain in the pen for a few days remain subordinate and perform poorly compared with higher rank primiparous and multiparous cows.

Effects of confinement

Normal stocking density

Confinement appears to increase levels of conflict, even in established groups of cows. Miller and Wood-Gush [18] monitored conflict interactions in a herd of 190 high-yielding cows on pasture during a grazing season and through the following winter confinement in a free-stall barn. Agonistic

interactions averaged 1.1 per cow per hour on pasture, but increased to 9.5 per hour in a confinement barn stocked at a rate of 0.9 cows per stall. Low-rank cows spent approximately 15% of their time in submissive or avoidance behavior in confinement, and their movements were frequently blocked by dominant cows in their paths.

Galindo and Broom [19] observed three dairy herds through a 5-month study of social rank, behavior, and lameness. In all herds, the stocking density was one cow per stall. Low-rank cows spent less time lying and more time standing still and standing half in the free stalls than middle- and high-rank cows. By 25 weeks into their lactations, more than 60% of the low-rank cows had become lame compared with 18% of the high-rank cows.

Overstocked conditions

When confinement barns are overstocked; defined here as whenever the number of cows in the pen exceeds the number of free stalls, social tension increases. Primiparous cows spent more time walking and lying outside of free stalls and showed a greater cortisol response to adrenocorticotrophic hormone (ACTH) challenge than multiparous cows in a mixed group stocked at 2 cows:1 stall [20], indicating an elevated level of stress in these animals. Overstocking can also refer to situations where the number of cows exceeds the number of eating spaces. Ethologists describe cattle as allelomimetic, meaning that they like to perform the same activity at the same time [18], which can apply to resting behavior, eating, drinking, and other activities. Overstocking, by definition, frustrates allelomimetic behavior.

Most modern free-stall pens are constructed with either two or three rows of stalls. Stalls are approximately 1.22 m (48") wide, while headlocks are located 0.6 m (24") on center. Thus, in a two-row configuration there are two feeding spaces for every two stalls. In contrast, in three row pens, feeding space per cow is reduced by one third. Studies of the effect of limiting feed-bunk space have produced mixed results. Using 24-hour video monitoring of high-producing cows in three-row barns, Menzi and Chase [21] showed that periods when the feed-bunk was occupied to capacity were few and of short duration, suggesting that there was much alternative time available when other cows could gain access to the feed. However, recent work has demonstrated changes in feeding behavior following fresh feed delivery in overstocked conditions [22,23]. In one study, when feed-bunk space per cow was reduced from 1.0 m to 0.5 m, spacing between cows decreased, there were increased aggressive interactions, and most importantly, subordinate cows reduced feeding activity within the 90-minute period after fresh feed delivery. In contrast, dominant cows showed no change in feeding activity with either spacing regimen [23].

Although dry cows generally have a low DMI compared with lactating cows, they may reduce intake when allelomimetic behavior is frustrated. Field data collected by Kenn Buelow [24] from two herds with dry cows

maintained in dry lots being fed a blended ration from a common source demonstrated a significant reduction in group DMI when cow numbers exceeded 92% of headlocks. Pregnant dry cows are wider than the typical two-foot spacing of headlocks, and the maximal filling rate of the feed bunk is likely achieved at less than one cow per headlock. Data collected by Gary Oetzel (personal communication, May 2004) demonstrates an effect of overstocking on mixed primiparous and multiparous groups during the prefresh period. Stocking densities greater than 80% of stalls in the prefresh group in a two-row pen adversely affected milk production of the primiparous cows through the first 83 days of the subsequent lactation. Modeling of data demonstrated that for each 10% increase in prefresh stocking density above 80%, there was a 0.73 kg per day decrease in milk production. Limited access to feed prepartum may also impact health. Cameron et al [25] showed that dry-cow feed bunk management had a negative impact on the incidence of displaced abomasum in a herd level model on 67 farms. Management was scored negatively if bunk space was less than 0.3 m (11.8") per cow, or if bunk space was 0.3 to 0.6 m (11.8"–23.6") and the ration was limit fed.

Interactions of rank and overstocking also influence stall access. Wierenga and Hopster [26] showed no significant effect of stocking densities of between 125% and 133% on stall access and resting time, but mean resting time for the group was adversely affected at 155%. However, when rank was evaluated, there were changes in behavior of low rank cows even at 125% stocking rates. As stall access was reduced, low-rank cows shifted lying behavior from night time into early evening hours when competition for stalls was less. At 155% stocking rates, this compensatory mechanism was overwhelmed as stall access in the evening also became reduced and total daily lying time could not be maintained.

Management of transition cow pen moves and stocking density

Very few behavior studies have been conducted using cows in the transition period. However, extrapolation of the findings suggests that effects on low rank individuals, and in particular, primiparous cows in mixed age groups, could be of great significance. A pen move introduces a period of social disruption lasting 2 to 3 days. Residency within a pen confers some elevation in rank of animals already in place. Small heifers will usually be subordinate to larger mature cows; however, cows losing weight, a common occurrence around calving time, may change rank. In any of the several pens that a cow visits during the transition process, agonistic interactions within a group will be amplified wherever overstocking occurs. Elsewhere in this book, Grummer and colleagues point out that the most important nutritional factor in determining metabolic disease in transition cows may not be the absolute level of DMI, but rather the change in DMI at the point of calving. Therefore, the risk of reduced intake following pen moves, and competition in

overstocked pens, may well be key determinants of transition cow success. Two critical control points for transition management are therefore to control stocking density changes in the prefresh, maternity and postfresh accommodation, and to limit the number of pen moves around calving time.

Control of stocking density

The size of the pens in a transition cow facility are usually based on some estimate of the proportion of the lactating herd that will be in a certain stage of the lactation cycle, depending on the target duration of stay in each group. Table 1 gives estimates for a 1000 cow lactating herd, but assumes a constant number of calvings per month. As the close-up dry pen consists of a small number of cows grouped together for a short period of time, it is continually in a state of flux. Control of stocking density in this group is difficult despite adequate planning, and may relate to occurrences during a few months in the summer in warm climates. It is common for fertility to be very depressed through July and August in many parts of North America. Following return to cooler conditions, the cows recover body condition and reproductive performance rebounds. This has a major impact on throughput through the transition cow facility, which may be understocked during April and May and extremely overstocked during July and August, right at the time when these cows will face the next round of heat stress. Adequate heat abatement measures for both lactating cows during the breeding period and transition

Table 1

Target group size, suggested housing type and duration of stay based on a proportion of the lactating cow herd for a new special needs facility

	% of Lactating herd	Number of cows in a 1000 lactating cow dairy	Housing type	Duration of stay (days)
Nonlactating group				
Far-dry	11	110	Free stall	35–40
Close-up mature cows	6	60	Free stall	21
Close-up heifers	3	30	Free stall	21
Maternity cows	1	10	Individual calving pen	2
Maternity heifers	1	10	Individual calving pen	2
Postfresh group				
Nonsaleable milk group	2	20	Free stall or Bedded pack	2 to 4
Fresh cows	6	60	Free stall	21
Fresh heifers	2	20	Free stall	14
Work group	3	30	Free stall	1
Treatment pen	3	30	Bedded pack	10
Lame cows	2.5	25	Bedded pack	21

cows are therefore vital for the control of throughput through the transition period.

Sizing of pens for the transition period is therefore helped by reviewing documentation of the historic calving pattern of the herd. It is helpful for expanding herds if dual purpose pens are constructed, which may be used for a variety of purposes, one of which would be carry over space for prefresh cows, should the need arise. We recommend the allocation of at least one stall per cow and, because of the increased girth of the pregnant cow, a minimum of 0.76 m (30") of linear bunk space per cow.

Limiting the number of pen moves for transition cows

Moving cattle between groups is inevitable on modern dairy farms. However, we suggest that the number of moves be limited as much as possible. Currently, most dairy advisors recommend a two-group dry period where cows are exposed to a close-up ration for the last 14 to 21 days before calving. However, Varga [27] argues that a minimum of 5 weeks of feeding a given ration may be required to establish a new metabolic plateau for liver and intestinal tissues. Shortened dry periods that use a single ration for the entire time are growing in popularity among progressive farmers [28,29] and benefits from this strategy may also accrue from a reduction in the number of group changes.

As calving becomes imminent, Mee suggests elsewhere in this issue that the ideal time to move the cow is 24 hours before calving. Unfortunately, a growing amount of field data and experience suggests that this timing is difficult to manage. Predicting calving time is unreliable, and cows may remain in the maternity pen for a week or more rather than 1 to 2 days as expected. Although the cows in a spacious maternity pen, lying down on a deep bed of clean dry straw may appear to be in an ideal environment for freshening, this may not be the case. Our field investigation experiences, based upon data from farms that maintained excellent records of pen move dates, suggest that nonesterified fatty acid (NEFA) concentration is elevated in a greater proportion of cows that have spent 3 or more days in the maternity pen than in cows that stay in the pen fewer than 3 days. The same farm records show that there is more than a twofold greater risk for ketosis and displaced abomasum (DA) for cows that stay on the maternity pack for 3 or more days, compared with cows that calve within 2 days on the pack (Garrett R. Oetzel, Madison, WI, personal communication, May 2004).

A calving management strategy that is finding favor in a growing number of medium- to large-size dairies involves moving the cow to a calving pen when the calf's feet begin to show. The practice presents some disadvantages; it requires around-the-clock monitoring of the close-up dry cow group with approximately hourly checks, and moving at this time may interrupt the calving process, particularly in heifers (see the article by Mee elsewhere in this issue). Once the calf is delivered and the cow has returned to her feet and is

able to walk without ataxia, she is transferred to the postfresh pen and the calf moved to the neonatal housing area. The duration of maternity pen stay is measured in hours rather than days.

Another possible strategy is to maintain several large bedded packs, similar to that shown in Fig. 2, and practice an all-in, all-out policy for the close-up cows. A group of cows expected to calve within a 2- to 3-week period would be moved into the prefresh pen, where they would remain until they calved. Subsequently, another group, representing the following 2 to 3 weeks of calving cows, would be moved to another similar pen, from which they too would calve and move into the postfresh accommodation. This strategy, which maintains small stable groups throughout the dry period has been made more feasible by the advent of shortened dry periods of 30 to 40 days. The approach does not obviate the need for regular checking of the pen so that the calf can be removed promptly without sucking (see the article by McGuirk and Collins elsewhere in this issue). Cows could freshen in the pen, or be moved to a calving pen as previously described. No new cows would be added until the pen is emptied, cleaned, and rebedded, completing the cycle. This strategy would almost completely remove the stresses of continually mixing cows.

In traditional grouping systems, the cow may be transferred from the calving pen to a nonsaleable milk pen for 2 to 4 days, or moved straight to a postfresh monitoring pen for 10 to 21 days. We prefer the latter strategy, as it removes a pen move, but it does mean that the milk must be diverted from the bulk tank when cows that are still under milk withdrawal are milked through the main parlor. Some individuals that have suffered milk fever or



Fig. 2. A correctly designed, well ventilated, loose housed straw bedded pack area for dry cows, with a bedding retainer, wide access to the bedded area and a concrete apron in front of the feed bunk.

calving difficulties may benefit from a short period of time in a smaller group away from more aggressive cows, however. Primiparous cows are uncommonly split from multiparous cows during the immediate postfresh period, primarily due to the convenience of health monitoring in a single group. However, there are undoubted benefits to grouping primiparous cows separately from multiparous cows after calving. Frequent milking of multiparous cows for 21 days or more after calving is facilitated by separating them from the primiparous cows, but in some herds, both are milked frequently in the same group for ease of management.

With these alternative strategies, the cow can proceed through the transition period with fewer pen moves and rank changes. However, for the strategies to work, the facility must be well designed, and the management excellent. We recognize five critical control points for these strategies to succeed:

1. Bedded pack management and hygiene must be excellent, necessitating the need for a plentiful supply of clean dry fresh bedding material on a well-designed, comfortable lying surface with excellent drainage.
2. The close-up pen must be checked frequently by a well trained person hourly, 24 hours per day
3. The close-up pen must be located immediately adjacent to the individual cow calving pens, so that the move at the time of delivery, if used, is easy and stress free.
4. The calving pens must also be located in an area away from cow traffic
5. Cows, and in particular heifers, must be allowed to progress through the stages of labor, without repeated disturbance following the guidelines for intervention described by Mee (elsewhere in this issue)

Problems will occur if a poorly trained individual is responsible for monitoring the close-up pen or if it is done infrequently. Calves sucking the wrong dam may lead to failure of passive transfer problems and breakdowns of disease control programs. If animals must be moved the length of the barn to the calving pen and not given time to deliver undisturbed—especially in the case of heifers, increased rates of dystocia and fetal death may occur (see the article by Mee elsewhere in this issue) [30]. Controlled data have yet to be collected to support the changes suggested, and this is an area in much need of research. However, several large farms are experimenting with these strategies, with apparent success in many cases.

Specific design considerations for a special needs facility

Pen layout, design, and flooring

Most new special needs facilities in large dairy herds in excess of 600 cows will usually add a treatment parlor in addition to the main parlor. For ease of machine maintenance and handling of waste milk for pasteurization, we

recommend that they be located adjacent to each other in one area of the farm.

Cows flow toward the milking centers, so those cows that may struggle to get to the parlor – such as lame cows, and those that must be milked more frequently, such as the postfresh multiparous cow group up to 21 days in milk, should be located nearest the parlor. A straw bedded pack on a separate limb of the barn provides an excellent place for lame cows to recover, and an additional pen adjacent may be used for treatment cows or new arrivals, so that they are isolated away from the main herd.

Precalving heifers and dry cows are most easily managed in small groups of approximately 30 cows on either bedded packs or in free stalls, with an area for individual calving pens immediately adjacent, should they be required depending on the grouping strategy being used. Located near these pens should be a storage area for pharmaceuticals and computer-record access. The barn design should have the flexibility to achieve the following after the cows calve:

1. Pen multiparous cows under milk withdrawal separately for milking through the treatment parlor
2. Pen multiparous fresh cows separate from primiparous cows for frequent milking 4 to 6 times per day up to 21 days in milk and for health monitoring. Fresh cows with antibiotic residue could be milked in the main parlor, but the milk would be diverted into a dump bucket. This group is deliberately located adjacent to the main parlor to reduce turn around time through the milking facility.
3. Pen primiparous cows separately for a monitoring period after calving, before they are moved to a separate pen elsewhere on the unit.

An automated sort gate can be located in the return lane to the main barn, so that cattle can be diverted into a work area for vaccination, hoof trimming, or other management tasks. The area should house a handling chute and hoof-trimming chute, along with another work station for storage of materials and computer access.

For a single person to move a cow from one area to another in the barn, an access lane, usually 2.44 m (8') wide, is essential (Fig. 3). This lane encircles the barn, and in each pen there is a set of sort gates in the corner. The gate arrangement has been described by Godden et al [31], and a modification is shown in Fig. 4. The gates allow for transfer of the cow, or examination in a simple head lock located adjacent to a stall.

There are three main options for stall layout within a pen, namely; three rows of stalls, or two rows of stalls head to head, or two rows of stalls tail to tail. We have already argued the case for access to feed earlier in the article; hence, we do not recommend three-row pens for transition cows. The decision between which two-row layout to use is not clear. With head-to-head stalls, there will be a row of stalls with easy access from the feed-bunk alley for timid cows, which may be bullied and inhibited from accessing



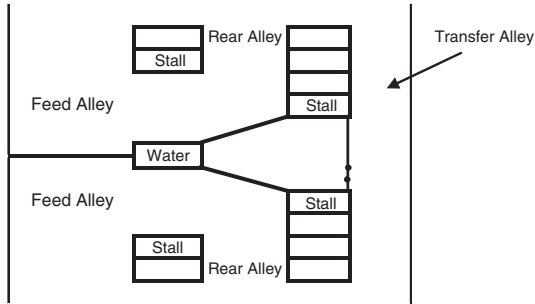
Fig. 3. A transfer alley used to move cows between pens in a well-managed transition cow facility. Although the front of the stalls are open, note the deterrent bar that is located too low to allow cows freedom to lunge forward in the stall.

a stall in a tail-to-tail design, where all cows must pass through a narrow access area to find a stall. However, the tail-to-tail design may be preferred where handling within the pen is important, as cows can be moved between the feed-bunk alley and the rear alley more conveniently. This may also facilitate manure removal with tractors in nonlactating groups that do not leave the pen for milking. We therefore suggest using the tail-to-tail layout for the special needs barn, but recommend providing a crossover every 18.3 m (60'). This may be easily achieved if we build pens for approximately 30 cows. For cows beyond the transition period, a head-to-head design can be tolerated, and probably carries some behavioral advantages with regard to stall access and lying times.

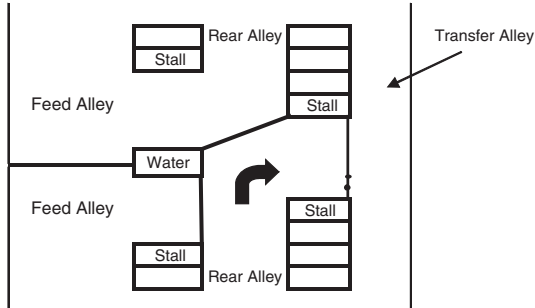
The rear alley in each pen should be at least 3 m (10') wide. The feed alley width should be at least 4 m (13') minimum in head-to-head pens, with stall access off the feed alley, and 3.66 m (12') in tail-to-tail pens. Alleys should slope 1.5% to allow drainage along their length and also slope away from the rear of the stall into the center of the alley, to avoid puddles of urine collecting beneath the rear curb. New designs in Europe provide slope to the center where urine and liquid feces pass below to a tunnel where a scraper moves the material to outdoor storage.

Flooring type is important, to prevent slippage and injury in animals that may be ataxic. Concrete and rubber are the commonest flooring materials used at present. If concrete is used, it must be 3500 psi air-entrained concrete, at least 0.13 m (4"–5") thick, and grooved to reduce slipping. Grooving methods and patterns have been reviewed in depth by Gooch [32]. Many barns have pen alleys with grooves running parallel to the long axis of

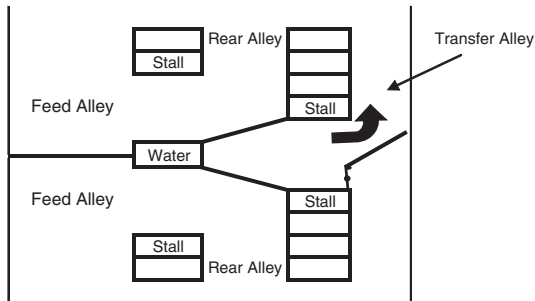
A. Normal position of gates



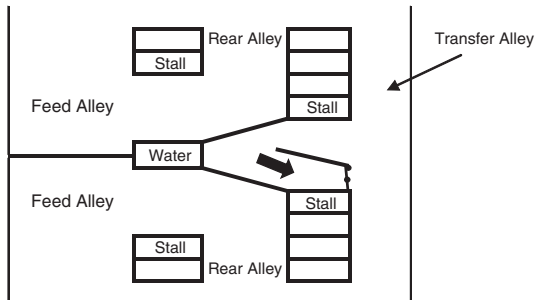
B. Cow is moved into the triangle



C. Cow may be transferred from the pen



D. Cow may be examined in a headlock



the pen, often located 0.1 to 0.15 m (4–6") apart. This does not appear to offer maximum slip resistance. Parallel grooves 1 to 1.3 cm (3/8"–2") wide and deep, spaced 5.1 to 7.6 cm (2"–3") on center, suggested by Graves et al [33] appear to offer a reasonable compromise between a pattern that has optimal nonslip characteristics and one that is too difficult to cut into the concrete. This pattern increases the likelihood that the cow's hoof will land on at least one groove as she walks, allowing manure trapped below the claw to be pushed along the grooves, facilitating contact between the concrete and the sole. This pattern may not, however, be sufficient for crossovers and high traffic areas where cows must make sharp turns. Here, a diamond pattern is preferred, created with an additional set of oblique channels also located 5.1 to 7.6 cm (2"–3") apart to add additional grip. It is generally easier to cut grooves into dry concrete rather than float grooves into wet concrete. However, whatever technique is used, the final product must result in: (1) a flat concrete surface between the grooves, rather than convex, and (2) smooth edges to the grooves, with little or no aggregate exposure. Once the floor has been grooved, it should be finished with a floor grinder to smooth the surface and remove sharp or broken edges that may damage the cow's feet if left untended.

In large facilities with long travel routes where hoof wear may be an issue, rubber flooring material is a logical choice over concrete. Various types of material exist, but the final product must provide cushion, while being resilient and nonslip. At the moment, however, the value of rubber surfaces in pen alleys is not clear. If stalls are poorly designed, the fitting of rubber may increase standing times in the alley, and may even lead to some cows lying in the alley. Two studies have documented a negative behavioral influence of rubber alleys [34,35], and one study found only a small benefit to claw health, and only in a pen with sand stalls rather than mattress stalls [36]. In order of importance, rubber flooring is most valuable in the sloped return alleys from the parlor, in the holding area for the parlor, along return alleys between the pens and the milking center, and finally along the feed alley in the pen, only if the free stalls are comfortable and well designed.

Current recommendations are for at least two water troughs for each group of cows and enough linear space for 15% to 20% of the group to drink at the same time [37]. This would equate to 8.9 to 12.2 cm (3.5"–4.8") of trough perimeter per cow. An ideal location for the trough is on the outside of each end of each pen, as it allows one trough to be shared by the cows from two adjacent pens.

Self-locking stanchions or "head locks" at the feeding fence are a useful way to manage and handle groups that require intensive monitoring. They are probably essential for the postfresh group. This is obviously not the



Fig. 4. Gate triangle design used for transferring cows from pens to a transfer alley, or to a lock-up for examination or treatment.

most appropriate time for a first lactation heifer to be introduced to head locks, and a period of training is beneficial [38]. Therefore, even the far-dry pens may need to have some head locks. It is wise to provide an additional area in each pen where the feed-bunk has only a post and rail, so that wary heifers can maintain DMI in a new situation.

Each pen should have a pass through 0.3 to 0.4 m (12"–16") wide at each end of the feeding fence to allow for the easy movement of herdsmen in and out of pens.

Heat abatement

Cooling of transition cows in hot climates is essential to maintain cow health, calf birth weights, and milk production in early lactation. By maintaining reproductive performance, it will also ensure even throughput through the facility. Smith et al [1] recommend two rows of fans—one over the feed bunk, and another over head-to-head stalls. To obtain the desired airflow of 800 to 1000 cfm per cow, they suggest that 1-m (36") diameter fans be spaced every 9.1 m (30'), angled down 15 to 25 degrees and hung 2 m (8') above the stall surface. If 1.2-m (48") fans are used, they should be spaced every 12.2 m (40') and mounted higher at 2.7 to 3.0 m (9'–10') above the stall. The fans should be activated above 21.1°C (70°F).

For additional cooling, low-pressure sprinklers (10–25 psi) may be used along the feed-bunk set to provide 0.11 L (0.03 gallons) of water per square foot of wetted area per sprinkler per cycle above temperatures of 21.1°C to 23.9°C (70°F –75°F). The wetted area should be set to cover the area 1.8 to 2.4 m (6'–8') behind the feed line and the water supply sized to supply the necessary flow rate of water. A standard cycle would be to have sprinklers on for 3 minutes and off for 12 minutes. However, soaking frequency may need to be increased to every 5 minutes during periods of severe heat stress. The nozzles on the water line are typically suspended at least 2.1 m (7') above the alley and 0.30 m to 0.46 m (12"–18") behind the feed line. The nozzles used in the barn should spray water in a 180° arc and they should be spaced according to their spray diameter—usually 1.8 to 2.4 m (6'–8') [39].

Stall design and bedding management

Stall design has been the subject of considerable interest and revision over the last 2 years [40,41]. An improved awareness of the needs of the cow in terms of surface cushion and traction, a defined surface area to lie upon, freedom from lunge, and "bob zone" (the area between the stall surface and a height of 1.22 m (40") at the most forward point of the lunge) obstructions, and room below and behind the neck rail to rise without hindrance, has led to a dramatic change in stall design recommendations [40]. Stall dimensions given here, and in detail in Table 2, will be based on a 636 kg (1400 lb) first lactation (primiparous) heifer a 727 kg (1600 lb) mature (multiparous) cow

Table 2

Recommended stall dimensions for first lactation (primiparous) heifers, mature (multiparous) cows, and multiparous pre-fresh cows

Stall Dimension meters (inches)	Recommendations		
	First lactation (636 kg)	Mature cow (727 kg)	Prefresh (818 kg)
Total stall length facing wall	2.74 (108)	3.05 (120)	3.05 (120)
Head-to-head platform	5.18 (204)	5.49 (216)	5.49 (216)
Stall length from rear curb to brisket board	1.73–1.78 (68–70)	1.78–1.83 (70–72)	1.83 (72)
Stall divider placement on center (width)	1.22 (48)	1.27 (50)	1.37 (54)
Height of brisket board	0.10 (4)	0.10 (4)	0.10 (4)
Height of lower divider rail (maximum)	0.30 (12)	0.30 (12)	0.30 (12)
Height below neck rail	1.22 (48)	1.27 (50)	1.27 (50)
Horizontal distance between rear curb and neck rail	1.73–1.78 (68–70) (minus width of rear curb in sand stalls)	1.78–1.83 (70–72) (minus width of rear curb in sand stalls)	1.83 (72) (minus width of rear curb in sand stalls)
Rear curb height	0.20 (8)	0.20 (8)	0.20 (8)

and an 818 kg (1800 lb) mature (multiparous) pre-fresh cow within three weeks of calving. Dimensions should be adjusted for smaller animals.

Stall surface

Ideally, the stall surface should be deep sand or other similar loose bedding material, maintained at a minimum depth of 15 to 20 cm (6"–8"). A loose bedding material that supplies both cushion and traction has been shown to have advantages over mats and mattresses with regard to use of stalls by lame cows and subsequent lameness prevalence [42,43]. Bedding retainers that would compromise cushion and trap contaminated sand in the bed should not be used. Fresh sand should be added at least weekly. Regular turnover of sand is essential for the maintenance of low bacterial counts. Coarse, washed mason sand will not clump as much as a fine sand, and manure-handling systems should be designed to cope with settling to accommodate this type of material. The sand should be leveled each milking, redistributing from the sides of the stall into the center. If fine sand is used, it may be necessary to remove the compacted material from the rear of the stall several times per year to prevent build up. Rodenburg [44] suggests filling the stall to the top of the rear curb and the brisket locator, giving the stall a 3% to 4% slope. After 7 days, the fill should have been reduced by 4 inches and the slope reduced to 1% to 2%.

If sand cannot be used, a mattress stall surface is a secondary option. In general, cows appear to prefer the most cushioned of these kinds of surfaces [45]. A cushioned mattress will still require the addition of a plentiful amount of bedding material if hock abrasion is to be limited and lying times

optimized. For mastitis prevention, the golden rule is that all of the organic bedding on a stall must be removed after 24 hours and fresh material applied daily. When operating this system, the type and size of the bedding particles becomes less important. Typically, kiln-dried sawdust provides a good cost effective option.

A defined surface area

The resting area of the cow should be defined in the front of the stall by a brisket locator that is smooth, rounded, and no higher than 10 cm (4") above the stall surface. Limited to this height, the cow can thrust her front leg forward during the rising movement. This movement is prevented in stalls with higher brisket locators, leading to aberrant standing behavior (Fig. 5). The locator helps position the cow in the stall when she is lying, helping to prevent entrapment in the front of the stall. All too commonly, boards 25 to 36 cm (10"–14") in height are used; hence, the term brisket board. We are not in favor of this design, and prefer to use the terminology suggested by Rodenburg [44] of a "locator" rather than a board. If wood is to be used, it should have a rounded edge and protrude above the stall surface no higher than 10 cm (4"). On no account should it be made of concrete, nor should the area behind the board be filled with concrete above the level of the stall surface. Filling this space prevents normal movement of the front leg during rising, and in certain situations may present a bob-zone obstruction. The rear edge of the brisket locator should be located 1.73 to 1.83 m (68"–72") from the rear lip of the curb, depending on the size of the cow. In loose bedded stalls,



Fig. 5. This cow has moved back on the stall and completes the rising movement with her rear legs in the alley, because the brisket locator is too high to allow the normal forward stride of the front leg.

efforts must be made to maintain bedding to within 4" of the top of the brisket locator so that the stall does not become dug out. High brisket locators will force cows to lie diagonally across the stall, creating the problem of excessive manure contamination in one corner of the stall immediately below the divider. In this position, however, the cow has a little more room for the forward stride of one front leg when rising, making it easier for her to use the stall. Width of the stall is measured on center between dividers. We would recommend 1.22 m (48") for a first lactation heifer, 1.27 m (50") for a postfresh mature cow and 1.37 m (54") for a prefresh cow in the close-up group—to allow for the increased girth of the heavily pregnant animal. Compromises may have to be made if age groups are mixed and in remodeled facilities. Recent work by Tucker et al [46] confirms that there are improvements in lying time and a reduction in perching, with the front two feet elevated on the stall platform in wider stalls.

Room to lunge and bob

In a tail-to-tail pen design, stalls should be 3.05 m (10') long to allow for front lunging in the largest cows in the herd. Where the stalls are not located immediately against a side wall, stall length maybe reduced to 2.74 m (9') as in Fig. 6. Stall dividers should not be mounted on horizontal mounting bars that may invade the "bob zone." They should be attached to vertical wooden posts anchored 1 m (36") deep into the ground, or employ a mounting system that leaves the front of the stall open. Head-to-head stalls should be built on a 5.5 m (18') platform, equivalent to two 2.74 m (9')



Fig. 6. An open front stall against a side wall, allowing uninhibited forward lunging of the head, free of obstruction. Dividers use a vertical mounting system at the bottom to avoid obstructing the lunge-and-bob movement of the head.

stalls facing each other [41]. Platforms less than 5.2 m (17') will lead to more heat stress during the summer as the cow's heads will be in close proximity. Social obstructions provided by an occupied stall will inhibit lunging of opposite cows into the forward lunge space, increasing diagonal lying and side lunging. To stop cows passing through the front of stalls, a deterrent wire wrapped in polypropylene tubing or a strap may be located 1.22 m (40–42") above the stall surface.

The design of the loop may vary, but the upper edge of the lower divider rail must be no more than 0.30 m (12") above the stall surface at the level of the brisket locator, and the upper edge of the upper divider rail should be located 1.22 to 1.27 m (48–50") above the stall surface. Some wide-loop designs now have an angled upper rail at the rear of the stall to allow unobstructed head movement as the cow backs and swivels out of the stall. There should be no more than 0.23 m (9") space between the end of the divider and the rear edge of the curb, so that cows do not walk along the rear of the beds. Rodenburg [43] notes that the location of the upturn of the lower divider rail is also of importance. Where this is located 0.61 to 0.76 m (24"–30") behind the brisket locator, bruising in the area of the last rib has been seen commonly. The recommendation is therefore to locate the upturn around 0.30 m (12") behind the brisket and no more. Locating the upturn further back toward the rear curb or rotating the divider through 180° has been used to enforce a straight lying position in the stall and reduce diagonal lying. This is unnecessary in a well-designed stall that provides room for front lunging, and has a correctly designed brisket locator that allows for the forward stride of the front leg, as most cows will lie straight when given the behavioral freedom to do so.

Space below and behind the neck rail

Although neck rail location does not appear to influence lying behavior in a stall, it does have an impact on standing behavior [47]. Correct location is problematic, and depends on the type of the stall being used. In a loose-bedded sand stall, its height will vary depending on the degree of sand fill. We suggest maintaining the height in the range 1.12 to 1.27 m (44"–50"). In mattress stalls it is now being suggested that the rail be positioned 1.22 to 1.27 m (48"–50") above the stall surface. Horizontal location is also important, and as a rule of thumb, the rear edge of the neck rail should be positioned directly above the brisket locator, so that it also is 1.73 to 1.83 m (68"–72") from the rear lip of the curb. However, producers should be prepared to make adjustments to its location, dependent on the size of the cows in the pen. The largest 25% of the cows should be able to stand squarely in the stall, with all four feet on the platform. In loose-bedded stalls with a raised curb, horizontal positioning is more complex. Cows will not stand with their rear feet on a sloped or rounded rear curb, and stand on the diagonal ahead of the curb if stall length allows (Fig. 7). To prevent excessive



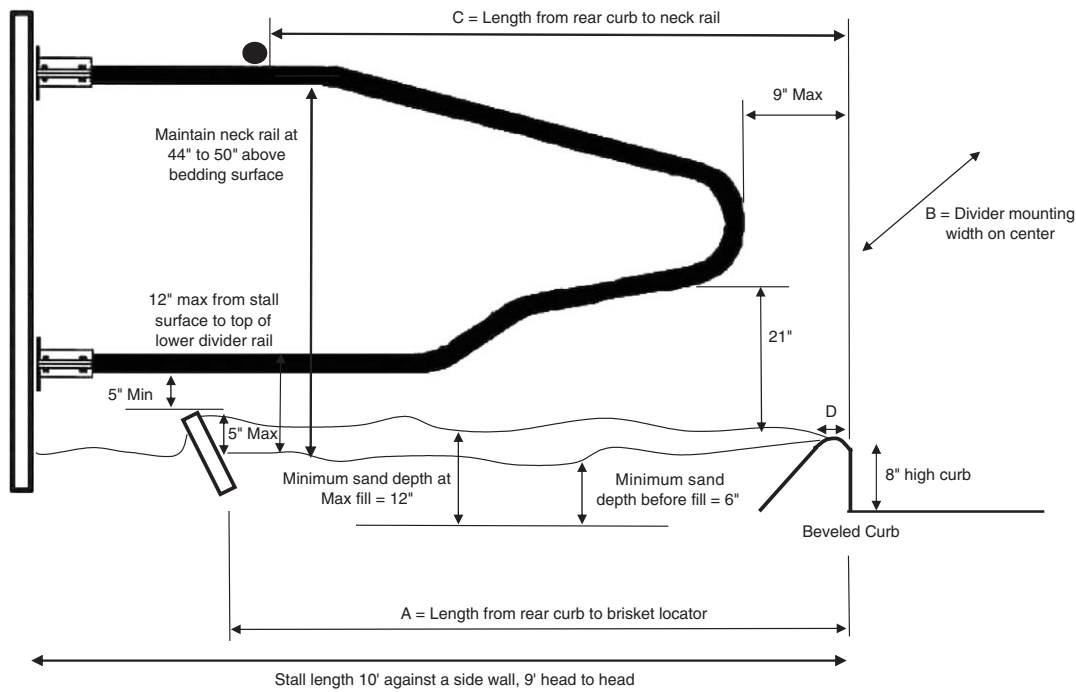
Fig. 7. Cows in loose bedded stalls will not stand with their rear feet on a rounded or sloped rear curb. This cow stands diagonally across the stall, avoiding the curb, but deposits manure on the rear of the stall.

soiling of the stall surface in this type of stall, the neck rail may need to be located nearer the rear curb. However, it is unacceptable for animals to hit the neck rail when rising in the stall. We suggest moving the neck rail from directly above the brisket locator back the width of the rear curb in a sand stall with at least 44" below the neck rail, essentially forcing cows standing in the stall to perch. We are prepared to tolerate this in a loose bedded sand stall because we know that lame cows do not spend prolonged times standing half in and half out of these stalls, compared with mattress stalls, and the degree of elevation of the front feet should they choose to do so is much less [43]. Obviously, the rear curb is an important part of the design of a loose-bedded stall. Our preference would be for the rear edge to be smooth and rounded off, and for the width to be as small as possible so as not to compromise the lying and standing area of the stall. An example design for a sand-bedded free stall is given in Fig. 8.

Maternity pens and calving pens

Cows may calve in individual calving pens or on a bedded pack maternity pen with the group. We have argued against the use of a short-stay maternity pen earlier in the article. However, up to 30 cows may be kept on a bedded pack for the duration of the dry period and calve there. Such areas are difficult to manage, but designs should be based on the following management principles:

1. The surface below the bedded pack area should drain well. Sand at least 30 to 46 cm (12–18") deep is one possibility, with deep-clean dry straw maintained above this.
2. The area should provide calving cows 11 m² (120 square feet) lying area per cow, with a 3.67 m (12') wide feed alley against the bunk.



Cow Pen Description	Dimension		
	A	B	C
First Lactation Milking Pen	70	48	A-D
Mature Cow Milking Pen	72	50	A-D
Pre-fresh Mature Cow Pen	72	54	A-D

Fig. 8. Sand bedded free-stall design using a wide-loop divider, with suggested dimensions for first lactation (primiparous) cows, mature (multiparous) cows, and multiparous prefresh cows.

3. The short side of the bed should be no more than 9.1 m (30'). Long narrow beds should be avoided, as cows will tend to walk to the back of the bed and lie down close to a wall as they leave the feed area. A short bed reduces the damage caused by this movement on and off the bedded area.
4. The bed should be demarcated from the concrete feed alley using a raised retainer made of concrete or wood.
5. Water access should never be from the bedded area. Water troughs maybe cut into the bedded area, enclosed with a three sided wall, with access only from the feed alley side.
6. Clean dry fresh bedding, such as straw, must be added daily at a rate of approximately 11.4 kg (25 lbs) per cow per day, and the whole bed removed every 3 to 4 weeks.

Calving pens, typically 3.65 m × 3.65 m (12' by 12'), should provide ample room for the animal to lie down in lateral recumbancy and allow room for the use of a calving aid if assisted delivery is required. It is useful to have a quick-release head lock in one corner and a wrap-around gate to help direct the cow into it. Gates should be mobile, so that they can be lifted out of the floor when the pen is cleaned. If organic bedding is to be used, the cow and calf must only come into contact with clean dry bedding. A concrete floor is a poor option, especially for compromised individuals weakened from a prolonged calving or hypocalcemia. A surface that provides good traction is therefore preferred—such as deep sand with clean dry fresh straw on top. Some newer facilities have mattress surfaces with organic bedding material on top, which provides cushion, traction and is easily cleaned between cows.

Building costs

The building of a special-needs facility that provides for housing, milking, diagnosis, and treatment is costly, and must be supported by improvements in health, milk yield, and reduced herd turnover rate. Smith et al [1] assembled costs for such a facility for cows from the close-up period through 14 days in milk, for a 2400 lactating-cow dairy herd. Total annual expense per cow, including bedding costs, interest on the loan, and a depreciation period of 10 years, ranged from \$23 to \$83.25, depending on the number of groups and whether a treatment parlor was included. Such an investment would require an extra 0.45 to 3.4 kg of milk per cow per day for break-even at typical milk prices. Improvements in health would also be expected, but cost savings are difficult to quantify. However, for the high-end facility, with the average cost of a fresh-cow health event (including milk fever, ketosis, retained placenta, and metritis) of \$320, a 2400-cow dairy herd would have to reduce the number of events by 625, or 26 per 100 cows. Such reductions are very achievable, if the facility contributes to their epidemiology.

Summary

Improved building designs come from a better understanding of the behavioral needs of the dairy cow. The costs to provide for these needs in the facility must be offset by improved milk production, health, and longevity. Research is still required to more fully understand the health implications of many building design considerations and their impact on disease. Perhaps the most important end result of an improved environment for the transition cow, however, is an improvement in animal well-being. Better buildings that accommodate the behavioral needs of cows present “win-win” situations where dairy cattle thrive and work is more enjoyable. This results in an improved image for the industry, greater consumer confidence in the quality and safety of the final food product, and a prosperous dairy industry.

References

- [1] Smith JF, Harner JP III, Brouk MJ. Special needs facilities. Recommendations for housing pregnant, lactating and sick cows. Manhattan (KS): Kansas State University Agricultural Experimental Station and Cooperative Service EP100; 2001.
- [2] Kondo S, Humik JF. Stabilization of social hierarchy in dairy cows. *Appl Anim Behav Sci* 1990;27(2):287–97.
- [3] Grant RJ, Albright JL. Effect of animal grouping on feeding behavior and intake of dairy cattle. *J Dairy Sci* 2001;84(E. Suppl.):E156–63.
- [4] Brakel WJ, Leis RA. Impact of social disorganization on behavior, milk yield, and body weight of dairy cows. *J Dairy Sci* 1976;59(4):716–21.
- [5] Sowerby ME, Polan CE. Milk production response to shifting cows between intraherd groups. *J Dairy Sci* 1978;61(4):455–60.
- [6] Hasegawa N, Nishiwaki A, Sugawara K, Ito I. The effects of social exchange between two groups of lactating primiparous heifers on milk production, dominance order, behavior and adrenocortical response. *Appl Anim Behav Sci* 1997;51(1–2):15–27.
- [7] Clark PW, Ricketts RE, Krause GF. Effect on milk yield of moving cows from group to group. *J Dairy Sci* 1977;60:769–72.
- [8] Collis KA, Kay SJ, Grant AJ, Quick AJ. The effect on social organization and milk production of minor group alterations in dairy cattle. *Appl Anim Ethol* 1979;5:103–11.
- [9] Takeda K, Sato S, Sugawara K. The number of farm mates influences social and maintenance behaviors of Japanese Black cows in a communal pasture. *Appl Anim Behav Sci* 2000;67:181–92.
- [10] Lamb RC. Relationship between cow behavior patterns and management systems to reduce stress. *J Dairy Sci* 1976;59(9):1630–6.
- [11] Dickson DP, Barr GR, Johnson LP, Wieckert DA. Social dominance and temperament of Holstein cows. *J Dairy Sci* 1970;53:904.
- [12] Arave CW. 1974. Unpublished data quoted in ref. 10.
- [13] Beilharz RG, Zeeb K. Social dominance in dairy cattle. *Appl Anim Ethol* 1982;8:79–97.
- [14] Schein MW, Fohrman MH. Social dominance relationships in a herd of dairy cattle. *Br J Anim Behav* 1955;3:45–50.
- [15] Hook SL, Donaldson SL, Albright JL. A study of social dominance behavior in young cattle. *Am Zool* 1965;5:714.
- [16] Phillips CJC, Rind MI. The effects on production and behavior of mixing uniparous and multiparous cows. *J Dairy Sci* 2001;84(11):2424–9.

- [17] Robinson PH, Moorby JM, Arana M, Hinders R, Graham T, Castelanelli L, et al. Influence of close-up dry period protein supplementation on productive and reproductive performance of Holstein cows in their subsequent lactation. *J Dairy Sci* 2001;84(10): 2273–83.
- [18] Miller K, Wood-Gush DGM. Some effects of housing on the social behavior of dairy cows. *Anim Prod* 1991;53:271–8.
- [19] Galindo F, Broom DM. The relationships between social behavior of dairy cows and the occurrence of lameness in three herds. *Res Vet Sci* 2000;69:75–9.
- [20] Gonzalez M, Yabuta AK, Galindo F. Behaviour and adrenal activity of first parturition and multiparous cows under a competitive situation. *Appl Anim Behav Sci* 2003;83(4): 259–66.
- [21] Menzi W, Chase LE. Feeding behavior of cows housed in freestall barns. In: *Dairy systems for the 21st century*. St. Joseph (MI): American Society of Agricultural Engineers; 1994. p. 829–31.
- [22] Batchelder TL. The impact of head gates and overcrowding on production and behavior patterns of lactating dairy cows. In: *Proceedings from the conference “Dairy housing and equipment systems: managing and planning for profitability,” NRAES-129, February 1–3, 2000*. Ithaca (NY): National Resource, Agriculture and Engineering Service; p. 325–30.
- [23] DeVries TJ, von Keyserlingk MAG, Weary DM. Effect of feeding space on the inter-cow distance, aggression, and feeding behavior of free-stall housed lactating dairy cows. *J Dairy Sci* 2004;87(5):1432–8.
- [24] Oetzel GR. Ketosis and hepatic lipidosis in dairy herds. In: *Proceedings from the 86th annual convention of the Wisconsin Veterinary Medical Association, Madison, WI; 2001*. p. 195–205.
- [25] Cameron REB, Dyk PB, Herdt TH, Kaneene JB, Miller R, Bucholtz HF, et al. Dry cow diet, management, and energy balance as risk factors for displaced abomasums in high producing dairy herds. *J Dairy Sci* 1998;81(1):132–9.
- [26] Wierenga HK, Hopster H. The significance of cubicles for the behaviour of dairy cows. *Appl Anim Behav Sci* 1990;26(4):309–37.
- [27] Varga GA. Energy levels in transition diets—enough but not too much. In: *Proceedings of the 35th annual convention American Association of Bovine Practitioners, Madison, WI, September 26–28, 2002*. Rome (GA): American Association of Bovine Practitioners. p. 131–8.
- [28] Bachman KC, Schairer ML. Bovine studies on optimal lengths of dry periods. *J Dairy Sci* 2003;86(10):3027–37.
- [29] Gulay MS, Hayen MJ, Bachman KC, Belloso T, Liboni M, Head HH. Milk production and feed intake of Holstein cows given short (30-d) or normal (60-d) dry periods. *J Dairy Sci* 2003;86(6):2030–8.
- [30] Dufty JH. The influence of various degrees of confinement and supervision on the incidence of dystockia and stillbirths in Hereford heifers. *N Z Vet J* 1979;29:44–8.
- [31] Godden S, Rapnicki P, Stewart S, Fetrow J, Farnsworth R. What we have learned at the transition management facility. In: *Proceedings of the 8th Ontario large herd operators dairy symposium; 2004*. p. 198–213.
- [32] Gooch CA. Flooring considerations for dairy cows. In: *Proceedings from building freestall barns and milking centers: methods and materials*. Ithaca (NY): Natural Resource, Agriculture, and Engineering Service, NRAES-148; 2003. p. 278–97.
- [33] Graves RE, McFarland DF, Tyson JT. *Penn State Dairy Housing Plans*. NRAES-85. 2nd edition. Ithaca (NY): Northeast Regional Agricultural Engineering Service; 1997. p. 102.
- [34] Fregonesi JA, Flower F, Vittie T, Tucker CB, Weary DM. Rubber flooring affects behavior of dairy cows, especially animals with hoof injuries. *J Dairy Sci* 2002;85(Suppl. 1):28 [abstract].
- [35] Leonard FC, Crilly J, O’Farrell KJ. Efficacy of currently recommended control measures for lameness in dairy cows. Teagasc Project Report 3981. 1998. Available at:<http://www.teagasc.ie/research/reports/dairyproduction/3981/eopr-3981.htm>

- [36] Vokey FJ, Guard CL, Erb HN, Galton DM. Effects of alley and stall surfaces on indices of claw and leg health in dairy cattle housed in a freestall barn. *J Dairy Sci* 2001;84(12): 2686–99.
- [37] McFarland DF. Freestall shelter design: meeting cow needs. In: *Proceedings from building freestall barns and milking centers: methods and materials*. Ithaca (NY): Natural Resource, Agriculture, and Engineering Service, NRAES-148; 2003. p. 42–64.
- [38] Brouk MJ, Smith JF, Harner JP III. Effect of feedline barrier on feed intake and milk production of dairy cattle. In: *Proceedings of the 5th international dairy housing conference*, Fort Worth, TX, January 29–31, 2003. St. Joseph (MI): ASAE. p. 192–5.
- [39] Harner JP, Smith JF, Brouk M, Murphy JP. *Sprinkler systems for cooling dairy cows at a feed line*. Manhattan (KS): Kansas State University Agricultural Experimental Station and Cooperative Service, MF-2401; 1999 .
- [40] Nordlund KV, Cook NB. A flowchart for evaluating dairy cow free stalls. *Bovine Practitioner* 2003;37(2):89–96.
- [41] Anderson N. Dairy cattle behavior: cows interacting with their work place. In: *Proceedings of 36th Annual Convention of American Association of Bovine Practitioners*, Columbus, OH; 2003. p. 10–22.
- [42] Cook NB. Prevalence of lameness among dairy cattle in Wisconsin as a function of housing type and stall surface. *J Am Vet Med Assoc* 2003;223(9):1324–8.
- [43] Cook NB, Bennett TB, Nordlund KN. Effect of free stall surface on daily activity patterns in dairy cows, with relevance to lameness prevalence. *J Dairy Sci*, in press.
- [44] Rodenburg J. Freestall construction and design. In: *Proceedings from building freestall barns and milking centers: methods and materials*. Ithaca (NY): Natural Resource, Agriculture, and Engineering Service, NRAES-148; 2003. p. 163–76.
- [45] Wagner-Storch AM, Palmer RW, Kammel DW. Factors affecting stall use for different free stall bases. *J Dairy Sci* 2003;86:2253–66.
- [46] Tucker CB, Weary DM, Fraser D. Free-stall dimensions: effects on preference and stall usage. *J Dairy Sci* 2004;87(5):1208–16.
- [47] Tucker CB. *The effects of free-stall surfaces and geometry on dairy cattle behavior*. PhD Thesis. University of British Columbia; 2003.