Environmental Design for Healthier and More Profitable Cows[1]

Jeffrey Rushen and Anne Marie de Passillé

Dairy and Swine Research and Development Centre, Agriculture and Agri-Food Canada, Lennoxville, QC J1M 1Z3 Canada. Email: rushenj@em.agr.ca

Take-home messages

- Stress, especially chronic stress resulting from poorly designed housing, can substantially reduce dairy cattles' health, welfare and productivity.
- Environments for dairy cattle should be designed so as to reduce stress on the animals.
- Resting time is important for dairy cattle. Poorly designed stalls for cattle, such as those that are too short or with inadequate flooring, lead to reduced occupancy of free-stalls, reduce the time the cattle spend resting and increase the chance of injury and lameness.
- High producing cows are more susceptible to stress so increases in production level need to go hand-in-hand with improvements in cow care and comfort.
- Chronic stress on heifers is likely to affect their health and performance as milking cows. The way that heifers are housed may help them adapt to the type of housing they will experience as adults.

Introduction:

The physiological and behavioural responses of dairy cattle to stress can reduce their productivity, their health and their welfare. Dairy cattle that have been selected for high milk production seem particularly susceptible to stress and are at more risk of behavioural, physiological and immune problems (Rauw et al 1998) and so require higher levels of care and management.

[1] Acknowledgement: We are grateful to the Federation of Dairy Producers of Quebec and NRI Industries Inc. for financial support.

Understanding how to design environments for dairy cattle so as to reduce stress is essential to maintain the long term profitability and sustainability of the dairy industry.

The economic impact of stress and reduced comfort means that dairy producers should not base their decisions on price alone, when buying equipment or constructing facilities. The impact on cow comfort must be understood. Unfortunately, there have been very few controlled scientific studies of the effects of stall design on the behaviour of cattle. A number of alternative designs for stalls and flooring for stalls are now on the market but have not yet been adequately evaluated for their impact on cow comfort. To evaluate the design of environments for cattle, we need simple yet valid measures of cow comfort, and we need to know more about which factors in the environment affect cow comfort. In this talk, we discuss some of the studies that have examined how the comfort of cows and heifers is affected by their environment, and suggest some simple ways that the level of cow comfort can be detected.

▪ Why Should I Care Whether My Cattle Are Comfortable?

Figure 1 shows some of the physiological systems that respond to stress and some of the undesirable effects of these changes on the animal.

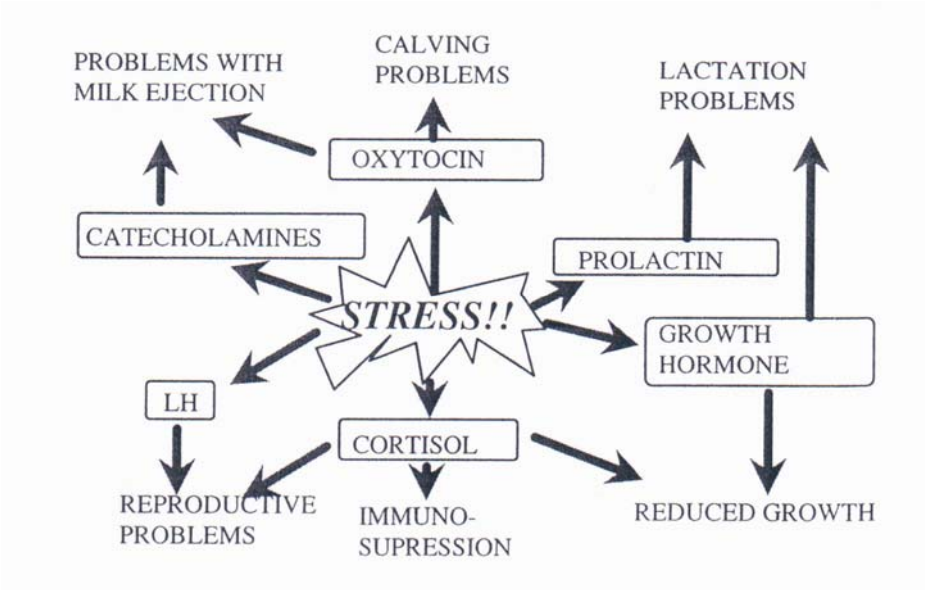

Figure 1. Hormonal changes resulting from stress.

This figure is based on a large amount of research that has been done using many species of animals, including dairy cattle. The main message of this figure is that "stress" is not something abstract, but that it has real, measurable, physiological effects on an animal that can greatly compromise that animal's health, welfare and productivity. These effects are particularly serious when the stress is chronic, or long lasting, as is the case when the stress arises from poorly designed housing environments. Although I am placing the emphasis on these physiological consequences of stress, dairy cattle also respond to stress with a number of behavioural changes, especially changes in the time spent eating and resting, which can be equally important for production. Furthermore, the animal's behaviour is often the best indicator that the animal is under stress. It is clear that, to ensure good health and productivity of dairy cattle, it is essential to identify the principal sources of stress, and to find effective and affordable ways of reducing this stress. Often we think of stress occurring when the animal is too hot or too cold. However, more subtle factors, such poorly designed stalls, can also stress cows. Improving the comfort of the cows is one way of reducing stress.

Ensuring the cows have adequate rest should be a major preoccupation of dairy producers when they make decisions about dairy housing. High producing dairy cows spend about 40-50% of the day lying down and adequate rest is necessary to ensure their high production. Blood flow to the udder is doubled when cows are lying down and, since cows tend to ruminate for longer periods when lying down compared to when standing up, maximizing the time spent laying down is important for optimizing rumination time.

Disturbed rest leads to physiological changes in cattle that are usually indicative of stress, and which are likely to affect health and milk production. For example, one study in Denmark found that cows that were prevented from lying down for certain periods of the day had plasma concentrations of growth hormone that were about 25% lower than cows that could rest whenever they wanted (Munksgaard and Lovendahl 1993). A German study (Ladewig and Smit 1989) found that bulls kept tethered on concrete floors were much more hesitant to lie down and lay down less than bulls that were kept on deep straw, and had higher levels of cortisol. As shown in Figure 1, these physiological changes could reduce the effectiveness of the immune system, making the animals more susceptible to disease. It is clear that to maintain high levels of production it is essential that dairy cattle are able to optimize their time spent resting.

Adequate sleep is especially important for the health and welfare of young animals. Adult cows sleep only about 4 hours a day (Ruckebush 1974), but young calves spend much more time sleeping. Like people, cattle have two types of sleep: slow wave sleep, and rapid eye movement sleep, when the brain is most active. These different phases of sleep may be important for the secretion of growth hormone. Although we have no data on this for cattle, in humans growth hormone secretion is clearly connected to sleep and occurs primarily during slow wave sleep, while in rats, growth hormone secretion

occurs mainly in rapid eye movement sleep. Danish research has shown that heifers that are able to spend more time resting are likely to have higher growth rates (Mogensen et al 1997a). Clearly it is essential to allow dairy cattle, especially younger animals, to sleep and rest adequately if we want to ensure their welfare, health and productivity

Uncomfortable stalls can also result in reduced stall occupancy in free stall housing. Some studies report a considerable incidence of cows, especially primiparous cows, refusing to use free stalls provided. In such cases, the cows usually sleep in the dunging area, which is likely to reduce hygiene. For example, one study in Ireland (O'Connell et al 1993) found that 77% of farms reported problems with some cows (ranging from 1- 47 % of the herd) lying outside of the stalls provided. Adding rubber mats to the stalls almost doubled the extent that the cows used them.

Injury to the animals is another undesired consequence of poor stall design, although apart from lameness we know little about the actual incidence of physical injury among dairy cattle. Surveys show the incidence of lameness to be between 30-50% but with considerable variation between farms (Whitaker et al. 1983; Clarkson et al 1996). However, the incidence of undetected hoof problems may be even greater. One study in Sweden reported visible lameness in 12-14% of the cows but closer examination of the hoofs showed that 70% of multiparous cows and 94% of primiparous cows had some signs of haemorrhaging of the sole, with most cases being unnoticed. In its "Report on the Welfare of Dairy Cattle", the UK Farm Animal Welfare Council stated that lameness is one of the main threats to dairy cattle welfare, and that the present incidence of lameness on dairy farms is unacceptable. This is equally true for Canada. The pain resulting from lameness is likely to be one of the most severe forms of discomfort suffered by dairy cattle. Lameness is also a substantial economic problem. Surveys in a number of countries estimate that each case of lameness costs several hundred dollars (Whitaker et al 1983; Greenough 1996; Enting et al 1997) in terms of lost production, reduced reproduction, and veterinary care. Involuntary culling for hoof and leg problems accounts for 3-4% of cows being culled in Quebec, especially among older cows (Dürr et al 1997). Unfortunately, selection for increased milk production appears to result in an increase in the incidence of lameness (Rauw et al 1998; Van Dorp et al 1998). Increases in production level therefore need to go hand-in-hand with improvements in cow care and comfort. The occurrence of lameness appears associated with nutritional problems or stress occurring around calving and so particular care needs to be paid to the housing of cows around calving. There is evidence that increasing the amount of time that cattle rest will lead to fewer leg problems (Leonard et al 1994).

▪ How Can I Tell if My Cows are Comfortable?

When cows find their stalls uncomfortable, they show this in their behaviour. A lack of comfort in free-stalls is apparent in reduced occupancy, with the cows sleeping in the concrete alleys or in front of the feeders. Alternatively, the cows will be seen standing with only their front legs in the stall. If this is seen often, it is a sign of a problem. Often there are also changes in the cow's daily pattern of rest/activity, especially an increase in the amount of time spent standing inactive. Close observation of how the cows get up and lay down can also give some information about the degree of comfort (Lidfors, 1989). Cows get up and lay down in a very fixed way (Figure 2) and the stalls must be designed to allow them to do this easily.

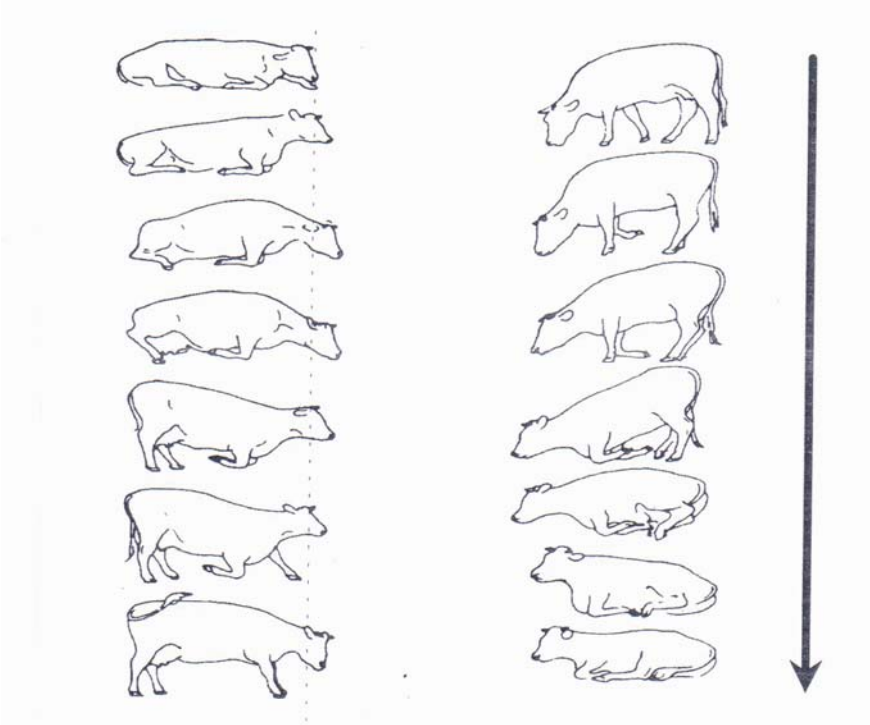

Figure 2. Sequence of behaviours when a cow gets up (left) and lies down (right). Dotted line show "lunge space" that cow's head moves forward. (Adapted from Lidfors, 1989)

The “lunge space”, that is the space that the head moves forward when the cow gets up can be seen in Figure 2. If the stall is too short, the cow may try to get up by rising on the front legs first. Alternatively, if the stall makes laying down difficult, the cows may show frequent hesitation before lying down, usually sniffing the ground. European studies (Muller et al 1993) found that cattle tethered on concrete floors showed longer periods of sniffing the floor prior to lying down, and more frequent bending of the front knees that were not followed by the cow laying down.

▪ What Determines How Comfortable The Cows Are?

Type of Housing Systems.

In Canada, dairy producers most often choose between tie-stalls or free-stalls, usually with an extra option of giving the cows access to pasture during summer. An obvious question is: which is better for the overall comfort of the cow? Since free-stalls do allow the cows extra exercise and some choice of lying place, they might seem better, provided that there are at least as many stalls as there are cows. A survey of several hundred farms in Norway did find some evidence of reduced ketosis and mastitis on free-stall farms than on tie-stall farms (Valde et al 1997). However, a study in Sweden (Bergestenn and Herlin 1996) found a greater incidence of hoof problems in cows in free-stalls than in tie-stalls. Cows kept in tie-stalls tended to have fewer heel erosions on their front hooves than on their back hooves, probably because the front of a tie-stall is usually cleaner and drier than the back of the stall. Cows in free stalls had equal number on their front and back hooves. A study in the UK found a higher incidence of lameness in cows kept in free stalls compared to cows kept in straw yards (Livesey et al 1998). Finally, not allowing heifers access to an outside yard has also been found to increase lameness (Vermunt and Greenough 1996). This raises the disturbing possibility that the present move towards free stalls in dairy production, particularly where the animals do not have access to pasture, may result in an increase in the incidence of lameness unless care is taken to improve the quality of the housing.

However, as we explain below, it is difficult to be categorical about differences between housing systems in the level of cow comfort, since the level of welfare within each system can vary greatly depending on the details of the system.

Stall design

Dairy cows in North America spend most of their lives in tie-stalls or free stalls, and so careful attention to the design of stalls is essential to maximize their health, productivity and longevity. Stalls should be designed so that the cow is comfortable when lying down, and, in the case of tie stalls, when standing. They must allow the cow to perform her natural movements when getting up and lying down so as to reduce the chance of the cow injuring herself.

Inadequate design of stalls can reduce stall occupancy in free-stall housing, and lead to injury, disturbed rest, and consequently lower production in tie-stall housing.

The size of the stall is obviously a critical factor affecting the degree of comfort, and recent recommendations for dimensions of free-stalls have been reasonably generous. The current Recommended Codes of Practice, suggest tie-stalls ranging from 60 X 44" to 72 X 56" and free-stall sizes up to 90" X 48". However, it is questionable whether even these dimensions will allow optimum comfort. In a recent study at Lennoxville, we compared resting behaviour of lactating cows kept in spacious pens (~3m X 3m) that were large enough to allow the cow to take up however much space she wanted to when lying down. We compared these to cows kept in conventional tie-stalls (72" X 48") and found that the cows in the larger pens spent about 1.5-2 hours longer per day lying down. Although allowing the cow too much space may result in problems of cleanliness, it is likely that we are still not providing the optimum space allowance for cows to maximize their comfort.

The comfort of a stall will depend greatly on the type and quality of the flooring in the stall. Under no circumstances should dairy cattle be expected to lie on bare concrete. A large survey of several hundred dairy herds in Norway (Valde et al 1997) found that simply providing a rubber mat or some litter bedding reduced the incidence of mastitis by 14% compared to cows kept on concrete floors. However, a few inches of straw or sawdust is probably inadequate to ensure the comfort of the animals

Optimal flooring should provide adequate thermal insulation, an appropriate degree of softness, appropriate degree of friction, a low risk of abrasion and should be easy to maintain and clean (Nilsson 1992). The importance of each characteristic will vary according to the species of the animal, their age and physiological state. For example, high producing dairy cows in peak lactation produce considerable heat, and so in a well-insulated or temperature controlled barn, the thermal properties of the flooring may not be critical. However, the shape and weight of dairy cows means that the softness of the flooring is critical to avoid injury and allow adequate rest. In contrast, for young calves or for cows that are kept in cold housing, the thermal insulation provided by the floor becomes important.

There has been considerable development recently in flooring types for stalls, with an emphasis on the development of softer flooring. Although various types of geotextile and rubber-based “mattresses” are available that are claimed to improve cow comfort, little evaluation has actually been done. In a recent study at Lennoxville, we compared lactating cows that were kept either on concrete floors with a small quantity of straw added, or cows that were kept either on geotextile “mattresses” or soft rubber mats. The results show some clear advantages of housing lactating dairy cows on softer mats or geotextile mattresses rather than on concrete. Most obviously, the cows housed on the mats lay down on average 1.5 hours longer each day (Figure 3). The use of

soft mats also halved the incidence of swellings, especially of the front knees, and thus seems likely to reduce the incidence of leg problems (Figure 4). Swollen knees and hocks usually come from the physical impact as the cow lies down and stands up, while abrasions and hair loss result from friction with the stall flooring. We found decreased knee swelling but no difference in the frequency of cuts, abrasions or hair loss with the use of softer mats. Therefore, the main advantage would seem to be in reducing the physical impact rather than reducing abrasiveness of the flooring. This is shown by the fact that the cows on softer mats showed an increased willingness both to lie down and to stand up. In fact, cows kept on the softer flooring stood up and lay down almost twice as often as cows on concrete (Figure 5). When they stood up, they also stayed standing for longer before lying down again. This suggests that the main advantages of the softer flooring are apparent when the animals are changing position. When both rising and standing, the cow's first movement results in her weight being put on the front knees (Figure 2). The reduced swelling of the front knees suggests that this movement is less painful for cows on softer mats, which would explain why they were willing to stand up and lie down more readily. Although the advantages of softer flooring are thought to lie in providing some extra cushioning for the bony protrusions of the cow when she is lying, our results suggest that reduced physical impact on the front knees may be equally or more important.

Stall flooring quality is also a major contributor to lameness: lameness has been found to be more frequent in heifers housed in stalls with a concrete floor compared to heifers housed in stalls with a rubber mat (Leonard et al 1994; Bergsten and Frank 1996). Providing heifers with some access to straw bedding also reduces hoof problems compared to when heifers are housed on fully slatted concrete floors (Hindhede et al 1996).

Increasing the softness of flooring can also increase the occupancy of free-stalls. O'Connell et al (1996) found a higher use (50%) of free-stalls by primiparous cows when the stalls were fitted with a rubber mat. Nilsson (1993) found that cattle will choose stalls primarily according to the softness of the flooring. Cows and heifers are more likely to be found standing with their front legs only in the stall when the flooring is concrete compared to when there is a rubber mat (Leonard et al 1994). This is one behavioural sign that the cows find the stalls uncomfortable. In Canada, Denis McKnight at Kemptville in Ontario found that cows prefer stalls bedded with a soft mattress, while their second choice was for stalls bedded with a rubber mat. These were preferred to rubber tires, wood or concrete.

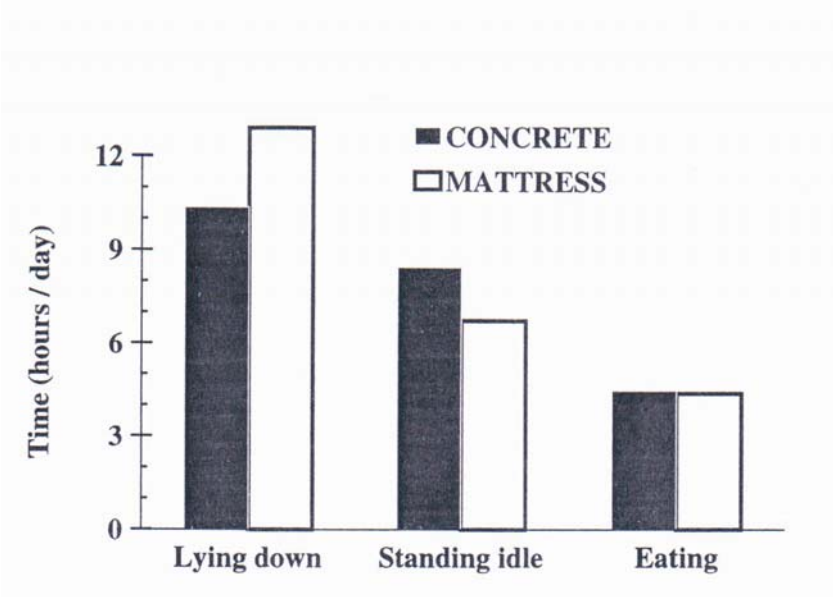

Figure 3. Mean time (h/d) spent lying, standing or eating of cows kept on concrete or on geotextile mattresses.

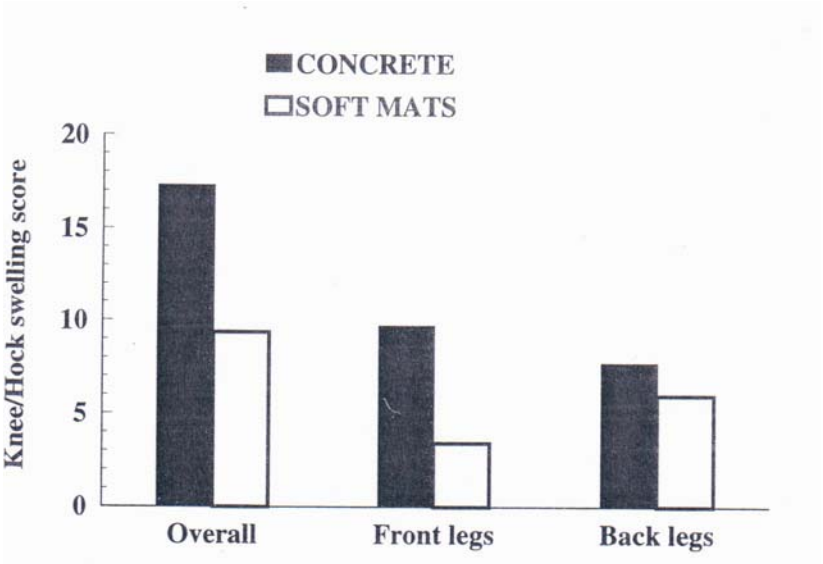

Figure 4. Swelling of knees and hocks of cows kept on concrete floor or on soft rubber mats.

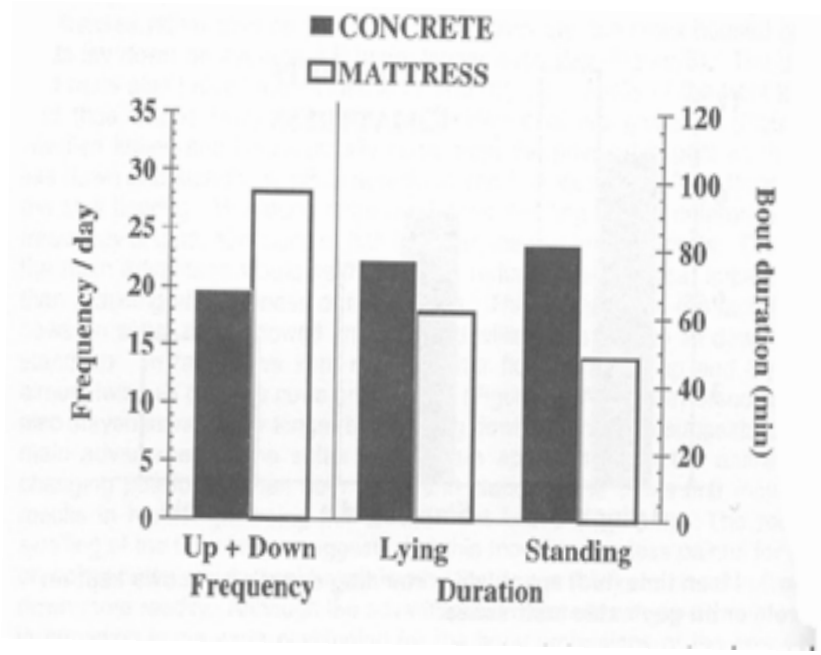

Figure 5. Frequency (mean number of times/day) that cows stood up and lay down and length of time they stayed in that position, for cows kept on concrete floor or geotextile mattresses.

Finally, the position of bars, drinkers, and partitions within the pen can also affect the level of comfort. Cows frequently bump into bars and partitions, often with considerable force, which is likely to lead to some bruising and injury. Cows get up and lie down in a very fixed way (Figure 2) and stalls must be designed to allow the cows to perform these natural behaviour patters so as to reduce the risk of injury. The lunge space (that is the space that the head moves forward) needed by a cow to stand up means that too little a distance between the brisket board and the front wall may make standing difficult. In tie-stalls as well, the design of the front of the stall can influence space use by the cow. A recent study at Lennoxville found that too narrow an opening between the stall and the feed area will mean that a cow is unlikely to lie down with its head in front of the stall front, and that the effective length of the stall will be reduced by several inches. Increased occupation of neighbouring stalls also occurred.

Although we have focused on the design of stalls, other parts of the barn can also affect cow comfort. For example, feeding tables or mangers that are flush with the floor of the stall greatly increase the pressure that the cow exerts on

the floor and on the bars of the feeder when eating. Raising the bottom of the feeder so that it is 20–25 cm above the level where the cow is standing can nearly halve the pressure that the cow exerts on the feeding bars (Gjestang 1983; Blom et al 1984/1985). This can be even further reduced if the front of the feeder is angled away from the cow and if the food is kept within easy reach of the cow.

▪ Group housing for younger animals.

In terms of comfort, the replacement heifer can probably be described as the "forgotten animal". Compared with the comfort of adult dairy cattle, very little is known about the best ways of housing heifers and young calves. What we particularly lack is information on whether or not the housing method chosen for the young heifer helps her adapt to the housing she will experience as a cow. The types of housing chosen for heifers is more variable than choice of housing for cows. Heifers can be found in individual stalls or crates, tie stalls, individual hutches, large groups on straw or in free stalls. Perhaps the biggest choice is whether the heifer should be housed individually or in groups.

Most of the research that has been done on housing for calves has focused on veal calves because of the widespread perception that the way veal calves are kept, especially milk fed calves, creates problems for their welfare. Certainly there can be some problems with individual housing, especially when the space allowance is too small, although, again, this is more often a problem for veal calves than replacement heifers. Limiting the space available to individually housed animals has been shown to lead to various physiological and immune signs of stress, and reduced growth rates if the degree of spatial restriction is large enough. For example, at Lennoxville, we recently compared calves that were reared until 5 months of age in identical individual pens that were either 2.1m or 0.6m wide. The latter were too narrow to allow the calves to turn or adopt normal resting postures. In the narrow pens, calves' growth rates were significantly reduced over 20 weeks, which was not due to reduced feed intakes. We also found some evidence of reduced growth hormone in these calves. Hopefully, not many dairy producers would keep their calves in these small spaces, but the results do show the potential dangers of not providing these young animals with enough space. Individual housing for heifers must be spacious and comfortable enough to allow the heifers to get up and lie down easily and to adopt the normal resting postures. Individual housing that is too small or uncomfortable may interfere with sleep.

European law now states that calves can only be kept in individual pens up to the age of 8 weeks, after which they must be kept in groups. There is some (as yet, very limited) evidence that where the cows are to be housed in groups then it may be preferable to house young heifers in groups in order that they have some opportunity to learn the social skills necessary to help them integrate into the group of older cows. One study in the UK (Broom and Leaver 1982)

compared calves that had been reared in groups with calves that had been reared individually and which were then later placed together in a group. The researchers found some evidence that the individually housed calves may show more social behaviour problems. We do not yet know at which age it is best to place the heifers in groups. Where adult cows are to be kept in free-stalls, there may be some advantages to training heifers to use free stalls before they are introduced to the adult herd. O'Connell et al (1996) found that the greatest occupancy of free stalls by pregnant heifers occurred when weaned heifers that had been housed in free stalls and had been trained to use them. The lowest occupancy was found when the heifers had been reared in group pens without individual stalls. Heifers that had been reared in stalls, but had not been trained to use them fell in between.

Unfortunately, most studies report higher mortality and disease when young calves are kept in groups, and dairy producers are often advised to minimize contact between unweaned calves to reduce the risk of disease transmission. However, some studies have found equal or lower levels of mortality when young calves are kept in groups. Some of these inconsistencies may relate both to the size of groups, the space allowance and method of feeding and use of bedding. The size of the group seems to be particularly important. A recent survey of calf housing in the US found that disease was highest in groups of more than six calves, while disease incidence in smaller groups was similar to that for individual housing (Losinger and Henrichs 1997). One factor that might increase disease transmission in grouped calves is the cross-sucking that occurs between calves. Dairy producers in particular are hesitant to keep heifers in groups because of this cross-sucking, which many believe leads to milk stealing. This behaviour usually only occurs while the calves are fed milk. However, this behaviour can be prevented or at least reduced in occurrence even in milk fed calves. The solution depends on realizing that, for calves, sucking is a reflex behaviour that is triggered by the taste of milk, and is relatively unaffected by the level of hunger of the calf. Even well-fed calves will be motivated to suck once they drink milk. Cross-sucking in calves usually occurs immediately after meals of milk rather than at other times, and can be reduced if the calves suck a teat immediately after the meal. Research at Lennoxville found that calves offered rubber teats after each meal preferred sucking the teat to sucking the other calves in the pen, so the teat had a marked effect on cross-sucking between calves by reducing its occurrence by more than 75%. Reduced cross-sucking is also likely to be found when calves drink their milk through a nipple rather than from a bucket.

When heifers are raised in groups it is important to avoid overcrowding. The space allowance in groups can also be important. Danish studies have found superior weight gains (~150-200 g/d) and superior food conversion efficiency when grouped heifers (300-400 kg) are kept with a space allowance of 2.7 - 3.6 m / calf compared to 1.5-1.8 m/calf (Mogensen et al 1997b; Hindhede et al 1996). These lower weight gains are often associated with reduced time spent lying down. Slatted concrete floors without bedding are not suitable for heifers and can increase the incidence of hoof problems (Hindhede et al 1996).

Although there is little or no knowledge about how the housing of young heifers can affect their later health and productivity, it seems most likely that chronic stress early in the life of the calf is likely to have deleterious effects on later performance. More attention needs to be paid to finding the optimum ways of housing dairy heifers so as to maximize their long term productivity, health and welfare. In addition, with the increasing use of free-stalls for adult cattle, we need to know whether there are any advantages in keeping heifers in groups in order to help them adapt to the group life they will experience as milking cows.

▪ References

1. Bergsten, C., & Frank, B. (1996). Sole haemorrhages in tied primiparous cows as an indicator of periparturient laminitis: effects of diet, flooring and season. Acta Veterinaria Scandinavia, 37, 383-394.
2. Bergsten, C., & Herlin, A. H. (1996). Sole haemorrhages and heel horn erosion in dairy cows: the influence of housing system on their prevalence and severity. Acta Veterinaria Scandanavia, 37, 395-405.
3. Blom, J. Y., Konggaard, S. P., Larsson, J. G., Nielsen, K., Northevd, A., & Solfjeld, P. (1984-1985). Electronic recording of pressure exerted by cows against structures in free-stall housing. Applied Animal Behaviour Science, 13, 41-46.
4. Broom, D. M., & Leaver, J. D. (1978). Effects of group-rearing or partial isolation on later social behaviour of calves. Animal Behaviour, 26, 1255-1263.
5. Clarkson, M. J., Downham, D. Y., Faull, J. W., Manson, F. J., Merritt, J. B., Murray, R. D., Russell, W. B., Sutherst, J. E., & Ward, W. R. (1996). Incidence and prevalence of lameness in cattle. The Veterinary Record, 138, 563-567.
6. Durr, J. W., Monardes, H. G., Cue, R. I., & Philpot, J. C. (1997). Culling in Quebec holstein herds. 2. Study of phenotypic trends in reasons for disposal. Cnadian Journal of Animal Science, 77, 601-608.
7. Enting, H., Kooij, D., Dijkhuizen, A. A., Huirne, R. B. M., & Noordhuizen-Stassen, E. N. (1997). Economic losses due to clinical lameness in dairy cattle. Livestock Production Science, 49, 259-267.
8. Gjestang, K.-E. (1982). Feeding table geometry in relation to dairy cow comfort. In Livestock Environment II. Proceedings of the 2nd International Livestock Environment Symposium (pp. pp433-437).
9. Greenough, P. R. (1996). Controlling lameness in dairy cattle. In: C. J. C. Phillips (Editor.), Progress in Dairy Science (pp. 191-210). CAB International.
10. Hindhede, J., Sorensen, J. T., Jensen, M. B., & and Krohn, C. C. (1996). Effect of space allowance, access to bedding, and flock size in slatted floor systems on the production and health of dairy heifers. Acta Agric. Scand. Sect. A. Animal Sci. 46, 46-53.

11. Ladewig, J., & Smidt, D. (1989). Behavior, episodic secretion of cortisol and adrenocortical reactivity in bulls subjected to tethering. Hormones and Behavior, 23, 344-360.
12. Leonard, F. C., O'Connell, J., & O'Farrell, K. (1994). Effect of different housing conditions on behaviour and foot lesions in Friesian heifers. The Veterinary Record, 134, 490-494.
13. Lidfors, L. (1989). The use of getting up and lying down movements in the evaluation of cattle environments. Veterinary Research Communications, 13, 307-324.
14. Livesey, C. T., Harrington, T., Johnston, A. M., May, S. A., & Metcalf, J. A. (1998). The effect of diet and housing on the development of sole haemorrhages, white line haemorrhages and heel erosions in Holstein hiefers. Animal Science, 67, 9-16.
15. Losinger, W. C., & Heinrichs, A. J. (1997). Management practices associated with high mortality among preweaned dairy heifers. Journal of Dairy Research, 64, 1-11.
16. Mogensen, L., Krohn, C. C., Sorensen, J. T., Hindhede, J., & Nielsen, L. H. (1997a). Association between resting behaviour and live weight gain in dairy heifers housed in pens with different space allowance and floor type. Applied Animal Behaviour Science, 55, 11-19.
17. Mogensen, L., Nielsen, L. H., Hindhede, J., Sorensen, J. T., & Krohn, C. C. (1997b). Effect of space allowance in deep bedding systems on resting behaviour, production, and health of dairy heifers. Acta Agricultura Scandanavia Section A: Animal Science, 47, 178-186.
18. Muller, C., Ladewig, J., Thielscher, H. H., & Smidt, D. (1989). Behavior and heart rate of heifers housed in tether stanchions without straw. Physiology and Behavior, 46, 751-754.
19. Munksgaard, L., & Lovendahl, P. (1993). Effects of social and physical stressors on growth hormone levels in dairy cows. Canadian Journal of Animal Science, 73, 847-853.
20. Nilsson, C. (1992). Walking and lying surfaces in livestock houses. In C. a. P. D. Phillips ((Eds)), Farm Animals and the Environment (pp. 93-110). Wallingford: CABI.
21. O'Connell, J. M., Giller, P. S., & Meaney, W. J. (1993). Weanling training and cubicle usage as heifers. Applied Animal Behaviour Science, 37, 185-195.
22. Rauw, W. M., Kanis, E., Noordhuizen-Stassen, E. N., & Grommers, F. J. (1998). Undesirable side effects of selection for high production efficiency in farm animals: a review. Livestock Production Science, 56, 15-33.
23. Ruckebusch, Y. (1974). Sleep deprivation in cattle. Brain Research, 78, 495-499.
24. Valde, J. P., Hird, D. W., Thurmond, M. C., & Osteras, O. (1997). Comparison of ketosis, clinical mastitis, somatic cell count, and reproductive performance between free stall and tie stall barns in Norwegian dairy herds with automatic feeding. Acta Vet Scand, 38, 181-192.

25. Van Dorp, T. E., Dekkers, J. C. M., Martin, S. W., & Noordhuizen, J. P. T. M. (1998). Genetic parametrs of health disorders, and relationships with 305-day milk yield and conformation traits of registered Holstein cows. Journal of Dairy Science, 81, 2264-2270.
26. Vermunt, J. J., & Greenough, P. R. (1996). Sole haemorrhages in dairy heifers managed under different underfoot and environmental conditions. British Veterinary Journal, 152, 57-73.
27. Whitaker, D. A., Kelly, J. M., & Smith, E. J. (1983). Incidence of lameness in dairy cows. The Veterinary Record, 113, 60-62.