The optimal free stall for dairy cows – Effects of free-stall design on cleanliness, milk yield, health, and behaviour

Optimal utforming av liggebås for mjølkeku –
Effekt på reinhet, mjølkeytelse, helse og atferd

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"Crazy gracing cow" *Drawing by Lars Lahlum Ruud*

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Animals may not be able to talk, but they can vote with their feet and express some of what they are feeling by where they choose to go

M. S. Dawkins

Contents

Sammendrag

Ruud, L.E., 2011. Optimal utforming av liggebås for mjølkeku - effekt på reinhet, mjølkeytelse, helse og atferd. Philosophiae Doctor Thesis 2011: 42, Universitetet for miljø- og biovitenskap. ISSN: 1503-1667, ISBN: 978-82-575-1005-3

Liggebåsens utforming er av stor betydning for blant annet hygiene og kuenes atferd i et løsdriftfjøs ettersom kua tilbringer hoveddelen av tida si her, hovedsakelig liggende men også stående i båsen. For å unngå at kua velger å legge seg andre steder enn i liggebåsen, må utformingen være slik at den utgjør den foretrukne liggeplassen. Dette innebærer at kyrne må tilbys en liggeplass tilpasset deres behov. Hovedmålsetningen med dette studiet var derfor å evaluere effekter av liggebåsutforming på reinhet, mjølkeytelse, helse og atferd. Denne avhandlingen er basert på tre delstudier; en spørreundersøkelse om liggeunderlag basert på 363 besetninger, et feltstudie i 232 besetninger og et kontrollert preferansestudie med 16 kyr. I dette studiet ble det funnet at liggeunderlag med en mjukhet på minimum 16 mm nedbøyning positivt hang sammen med økt mjølkeytelse (+ 3.9 til 4.5 %) og redusert forekomst av mastitt (inntil 19.9 % reduksjon eller 2.8 prosentpoeng) og spenetråkk (inntil 82.4 % reduksjon eller 1.4 prosentpoeng), mens betong som liggeunderlag er en risikofaktor for utrangering. Studiet har videre vist at detaljer i utformingen av liggebåsen er viktig for både dyras og båsens reinhet, noe som også virker inn på jurhelse og mjølkekvalitet. Det ble funnet sammenhenger der følgende forutsetninger var av betydning for reine båser; bruk av strø (> 0.2 liter per bås), avstand diagonalt fra oppkant bak i bås til nakkebom bør ikke overstige 1.96 m, nedre hodebom i front av båsen bør fjernes, båsens lengde bør ikke være lenger enn 2.30/ 2.45 m, brystplanke med høyde på maksimum 0.1 m bør brukes, men den har mindre effekt på båsreinhet dersom den plasseres mer enn 1.83 m fra bakkant i båsen. Øvre hodebom bør plasseres minimum 0.7 eller helst opp mot 1.0 m over golv i liggebås. Bredde og lengde hadde betydning for reinhet, men mindre enn forventet. I tillegg til andre parametre som påvirker reinhet, viser dette studiet at det er av stor betydning for båsreinhet at fronten av liggebåsen er av en åpen konstruksjon, antakeligvis fordi dette i minst mulig grad innvirker på dyras naturlige legge- og reisebevegelse. Det ble også funnet at følgende variabler var risikofaktorer for skitne kyr; bruk av lite strø (< 0.5 l per bås), ”tett” liggebåsfront, flere enn ei ku per liggebås, lite tamme kyr samt høy eller lav temperatur og høy relativ luftfuktighet. I et kontrollert forsøk hvor fleksible båsskiller av enkel utførelse ble sammenliknet med tradisjonelle fritthengende båsskiller med tanke på dyras liggeatferd, ble det funnet at de fungerte like godt. Utformingen av liggebåsene i dette forsøket var basert på funn nevnt over som bidro til reine båser og kyr. Det ble ikke funnet forskjeller i liggeatferd, men kuene viste likevel en klar preferanse for de fleksible båsskillene. Båsene holdt seg bemerkelsesverdig reine under hele forsøket.

Abstract

Ruud, L.E., 2011. The optimal free stall for dairy cows - effects of free-stall design on cleanliness, milk yield, health, and behaviour. Philosophiae Doctor Thesis 2011: 42, Norwegian University of Life Sciences. ISSN: 1503-1667, ISBN: 978-82-575-1005-3

Design of the free stall is of major importance to e.g. cleanliness and cow behaviour because the cows spend the majority of their time in the stalls, mostly lying but also standing. To avoid that cows chose to lie other places than in the free stalls, the design has to be such that it is the preferred place for lying. An implication of this is that the free stall has to be adapted to the demands of the cows. The main aim of this study was therefore to evaluate effects of free stall design on cleanliness, milk yield, health and behaviour. The thesis is based on three studies; one questionnaire about free stall base in 363 dairy herds, one field study in 232 dairy herds and one controlled preference test with 16 dairy cows. In present study it was found that soft stall bases with a minimum softness of 16 mm impact was associated with increased milk yield (+ 3.9 to 4.5 %), decreased incidence of clinical mastitis (up to 19.9 % reduction or 2.8 percent points) and teat lesions (up to 82.4 % reduction or 1.4 percent points), whereas concrete as lying surface seem to be a risk factor regarding removal. Present study also found that details of the free stall design are of importance for stall and animal cleanliness, factors influencing on udder health and milk quality. Clean stalls were associated with use of bedding (> 0.2 L per stall), maximum diagonal distance from rear curb in stall to neck rail of 1.96 m, lower head rail not present, length of stall base not more than 2.30/ 2.45 m, and brisket locator with maximum height 0.1 m should be used. However, the effect on stall cleanliness is minor if located more than 1.83 m from rear curb. Upper head rail should be positioned minimum 0.7 or preferably closer to 1.0 m above stall floor. Associations between stall cleanliness and stall width and length was found, however were of less importance than expected. It was found that an open front in free stalls is of importance for stall cleanliness, possibly because an open front will interfere less with the lying and raising movements of the cows. Further, the following variables were found to be risk factors for dirty cows; use of less than 0.5 L bedding per stall, less open front in the stall, increasing cow number per stall, less tame cows and high or low temperature and high relative air humidity. Flexible dividers performed equally good as standard fixed cantilever stall dividers with regard to lying behaviour of the animals in a controlled study comparing flexible and fixed stall dividers. The design of the stalls was based on the findings that contributed to increased stall and cow cleanliness mentioned above. The cows clearly preferred stalls with flexible dividers, however no differences in lying behaviour were found. The stalls remained remarkably clean during the experiment.

List of original papers

This thesis is based on the following original papers and they are referred to by their roman numerals in the text:

Paper I

Ruud, L.E., K.E. Bøe, and O. Østerås. 2010. Associations of soft flooring materials in free-stalls with milk yield, clinical mastitis, teat lesions, and removal of dairy cows. J. Dairy Sci. 93: 1578-1586.

Paper II

Ruud, L.E., C. Kielland, O. Østerås, and K.E. Bøe. 2011. Free-stall cleanliness is affected by stall design. Livestock Sci. 135: 265-273.

Paper III

Ruud, L.E., K.E. Bøe, and O. Østerås. 2010. Risk factors for dirty dairy cows in Norwegian freestall systems. J. Dairy Sci. 93: 5216-5224.

Paper IV

Ruud, L.E., and K.E. Bøe. 2011. Flexible and fixed partitions in free stalls – effects on lying behavior and cow preference. Accepted for publication in J. Dairy Sci. Doi:10.3168.

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Introduction

Under natural conditions cattle are gregarious animals searching for i.e. food, water, safety and comfortable resting places in the nature (Albright and Arave, 1997). Due to domestication man has taken the responsibility to take care for them and also to supply them with a proper housing system. Basic demands of cattle are access to food, water, weather sheltering etc. as described in the five freedoms of the Brambell committee (Brambell, 1965), further including the need for a proper resting place. Hence stall design is of importance for animal welfare. Because farmed cows do spend most of their time lying in a stall, it is important that the resting place is designed according to the needs of the cow and with adequate space for performing behaviour typical for the species. A defined, protected and suitable place for lying, allowing normal resting and lying behaviour is therefore aimed. A proper lying place for dairy cows should protect the animal in all means without restrictions hindering normal raising and lying down movements of the cows. There should also be a soft surface to lie on to attain comfortable rest and sufficient resting time. A lying place that is hygienic and also easy to manage for the farmer is preferable. Clean animals and hygienic housing conditions are important premises to achieve high production standards and hygienic dairy products. Successful design of the resting place is thus a prerequisite for and also of major importance to the dairy production with regard to animal welfare, health and production income.

Under Scandinavian conditions, there is a higher need to protect cows using a suitable shelter and housing system due to the climate, than is the case in more southern countries. The location with long and cold winters means that most dairy cows are kept in insulated buildings. Traditionally, cows have been housed in tie-stall systems and as late as the 1980ies, group housing systems were very seldom found in Norway. In 1989 about 2 % of the cows were housed in a group housing system (Bøe, 1993). In 2005 13.6 % of the herds or approximately 23.8 % of the Norwegian cow population were group housed and more than 97 % of all group housed herds used free stalls (Simensen et al., 2010).

There exist several types of group housing for dairy cattle; group housing on straw, deep bedded packs, combined feeding-resting stalls and freestalls. Due to restricted access to good bedding materials (dry straw, sawdust and sand) in parts of Norway, free stalls with mats or mattresses are often preferred. In 2009 the mean herd size in the Norwegian Dairy

Herd Recording System (NDHRS) was 20.5 cow-years (cow-year = number of days within a herd from first calving to culling within one year, divided by 365, corresponding to mean number of cows in the herd at any time) and today there are still only 14 farms with more than 100 cow-years registered in this system (NCHS, 2010). Hence, the herds are small compared to other countries. Early in the 19th century when modern loose housing systems were first introduced, reasons for choosing such systems were to reduce the work load. Group based systems have a potential for better animal welfare, and this is partly the reason for a moving towards group housing both in cattle, pigs and hens (St.meld. 12, 2002). "Success" with group housing is, however, dependent also on management, barn layout and stall design. Bakken et al. (1988) found group housing in dairy production to be associated with better fertility and health (mastitis, ketosis and total number of diseases) compared to tie-stall housing.

In European English terminology the word for free stall is "cubicle". As this dissertation is written in UK English, this should normally have been the term used. However, three out of four papers being a part of this dissertation are either published in or submitted to US journals. Because of this, the term "free stall" is used consequently throughout the dissertation.

The "optimal" free stall

Fregonesi et al. (2009b) found cows to prefer an open pack area compared to relatively comfortable free stalls, however, differences were small. Compared to loose housing, the main difference is that the lying area in a freestall housing system is distributed into individually protected places for lying that also implies an intended orientation of the cow when resting. The restrictions of the free stall are used mainly to control defecation behaviour (Tucker et al., 2005) and further to save space, labour and bedding material (Scmisseur et al., 1966). Implications of using a stall construction with several fixed restrictions, is that normal behaviour during rest, lying down and raising may be influenced or restricted (e.g. Bernardi et al., 2009). When working on optimisation of stall design, one has to keep in mind that design and management parameters may also have other effects than investigated or even negative effects on other traits (Tucker and Weary, 2001). One example may be that larger stalls are positive for the lying time of the animals, however is associated with more dirt in stalls (Tucker et al., 2005).

To be preferred and used by the cows, the “optimal” free stall should be designed according to the behavioural needs of the cows and thus an attractive place for the cow to lie in (Tucker et al., 2003-2006). The optimal stall design should contribute to high milk yield, good udder health and normal behaviour. Therefore recommendations are to provide the cow with an individual, defined, protected, and comfortable place for lying and standing designed such that hygienic conditions, normal lying time, lying down and raising behaviour are attained (Ruud et al., 2005). Lying time per day as well as cleanliness, milk yield, health, and behaviour may all be influenced by factors like properties of the lying surface, the design of the stall itself as well as other factors (Potter and Broom, 1987). Hence, these factors are often used as indicators of how good the function of a housing system or a free stall is, e.g. Manninen et al. (2002), Rushen et al. (2001), Tucker (2003) and Tucker et al. (2003-2006).

Cow cleanliness influences on milk and slaughter hygiene, sustains good udder health (e.g. Barkema et al, 1998; Schreiner and Ruegg, 2003; Zdanowicz et al., 2004; Reneau et al., 2005; DePalo et al., 2006; Munoz et al., 2008; Breen et al., 2009), and influences on thermoregulation (dirty and wet) (Hamada, 1971). Different methods for assessing animal cleanliness are used (Edmonson et al., 1989; Chiappini et al, 1994; Hultgren and Bergsten, 2001; Hughes, 2001; Schreiner and Ruegg, 2003; Gygax et al., 2007; Lombard et al., 2010), however, the score will always imply some part of subjectivity. The legs, belly and thigh are usually the dirtiest body parts, whereas udders normally are cleaner because of being cleaned daily in connection to milking (Veissier et al., 2004). Stall cleanliness is normally assessed similarly as cow cleanliness. The link from stall cleanliness to mastitis and farmer income is not very well documented and the knowledge about e.g. the total costs for the farmer due to dirty stalls and cows seems to be scarce.

Milk yield, mastitis, teat lesions and removal are important indicators of success in free stall design (Tucker and Weary, 2001). Calamari et al. (2009) found positive effects of free stall surfaces on milk yield in the later part of lactation, indicating a link between softness and milk yield, however, no other documentation with statistically significant effects of stall base softness on milk yield seem to exist despite often being claimed (e.g. Albright and Arave, 1997; Haley et al. 1999; Chaplin et al., 2000; Rushen et al., 2001). Milk yield is significantly decreased by clinical mastitis (Rajala-Schultz et al., 1999; Gröhn et al., 2004; Wilson et al., 2004; Halasa et al., 2007) and all precautions that can reduce the incidence of clinical mastitis are therefore positive. For the year 2005, an incidence rate for severe/ moderat clinical mastitis of 14.9 per 100 cow years was found in a study of the Norwegian Cattle Health Recording system (Østerås et al., 2007). As teat lesions make it easier for bacterias to colonize and hence increase the infectious load, full integrity of the teat canal is important as a primary defence mechanism against mastitis. Culling or removal of cows are sometimes used to describe the influence of the production environment on the cows (e.g. Gröhn et al. 1997), however the reason for cows to be removed from a herd is complex and consists of reasons ranging from diseases and accidents to being a part of normal recruitment (Hadley et al., 2006).

The history of the free stall

The free-stall system seems to be invented in the late 1950ies by Major Bramley, UK (Bramley, 1962). His idea was to utilize plastic foam mattresses as bedding instead of straw in yards, mainly to reduce the need for bedding material. However, he soon realized that the animals had to be restricted in some way in order not to foul their bedding or get dirty when lying down. The solution was the free-stall. For optimal function, the free stall design has to be designed according to "animal demands", very well pinpointed by Major Bramley himself; *"The size of the cubicle must be adequate to enable the animal to stand and lie down in comfort but at the same time its positioning must be reasonable accurate, and the permissible margin of movement restricted so that it cannot stand forward or move sideways sufficiently to enable it to dung and urinate on the bedding".*

It is interesting that the inventor of the system already from the very beginning used soft mattresses and focused on stall size versus space needed for performing natural behaviour and movements. According to his article, Bramley visited some farms and universities in USA, and it seems like his idea was soon adapted to American conditions. Adolph Oien in Washington was probably the first American farmer to use free stalls (Albright, 1964). Expanding farmers appreciated the system due to saving straw material (Tillie, 1986) and work load (Schmisseur et al., 1966) and it soon became widespread in large herds in USA and later in Europe.

Compared to modern free stalls, Bramley's stall was short and wide. No neck rail was installed, whereas a horizontal rail at the entrance was used, possibly for hindering cows in heat in riding into the stalls. In the front of the stall there was an opening for the head between vertical bars. Major Bramley equipped his stalls with soft foamy mattresses

(Figure 1: left); however, the article tells nothing about the softness and durability of these. The free stall of Adolph Oien was with solid dividers between each stall (Figure 1: right). Based on this photo, it looks like the stall base is deep-bedded with straw and that the stall base was levelled approximately 0.2 m from the floor in the alley (Albright, 1964). Most design trends found in modern free-stalls today therefore seem to be implemented already in these early pioneer-stalls. In the beginning free stalls were usually home-made based on the farmers own ideas (Tillie, 1986). Major development since this time is introduction of open cantilever stall dividers (Figure 2), number and position of rails, brisket locator as well as several types of pre-made and soft free-stall bases. Much of the development of the free stall through the years seems to be industry driven. However, several studies on different aspects of the free stall design are performed, for example; hygiene (Tucker et al., 2003-2006; Veissier et al., 2004; Fregonesi et al., 2009a), lesions (Weary and Taszkun, 2000; Rushen et al., 2007; Kielland et al., 2009), behaviour (Rushen et al., 2001; Manninen et al., 2002; Overton et al., 2002; Cook et al., 2005), and health (Cook et al., 2004).

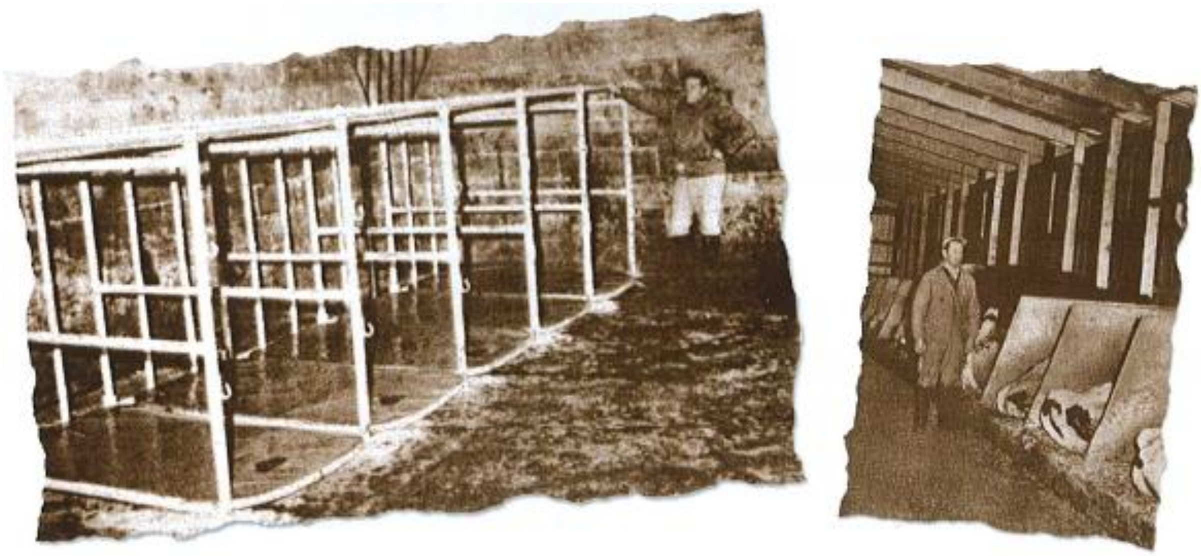

Figure 1. *Major Bramley seems to be the inventor of the free stall system (left; picture from Bramley, 1962). The system was first used in America by Adolph Oien (right; picture from Albright, 1964).*

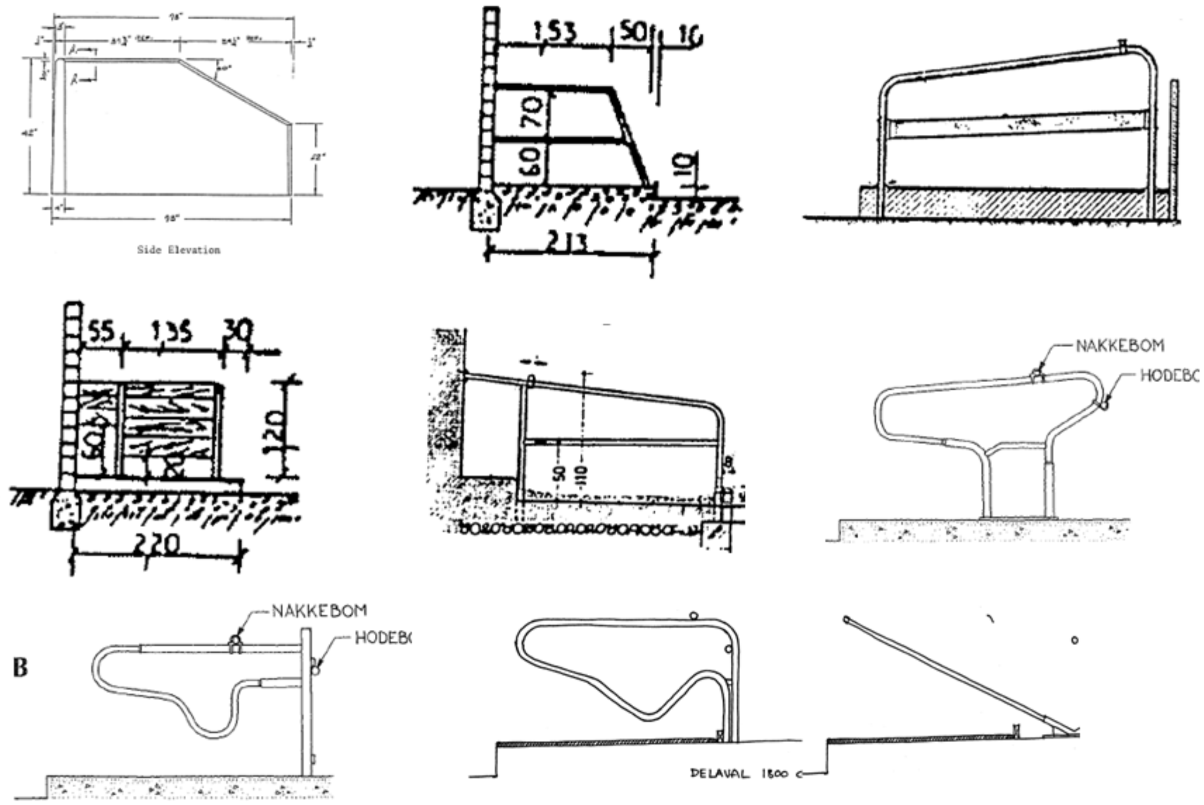

Figure 2. *The free stall design has developed against more open designs during the decades since invention. Figures are intended to show the trend in the development of free stall design (Figures adopted from Tillie, 1986; Gjestang et al., 1999; own drawings).*

The components of a free stall

The major components of a free stall are the surface for lying (the free stall base), the rails intended to define lengthwise space in the stall accessible for the cow (the head and neck rails and brisket locator) and the stall components defining accessible space laterally in stall (the stall dividers) (Figure 3).

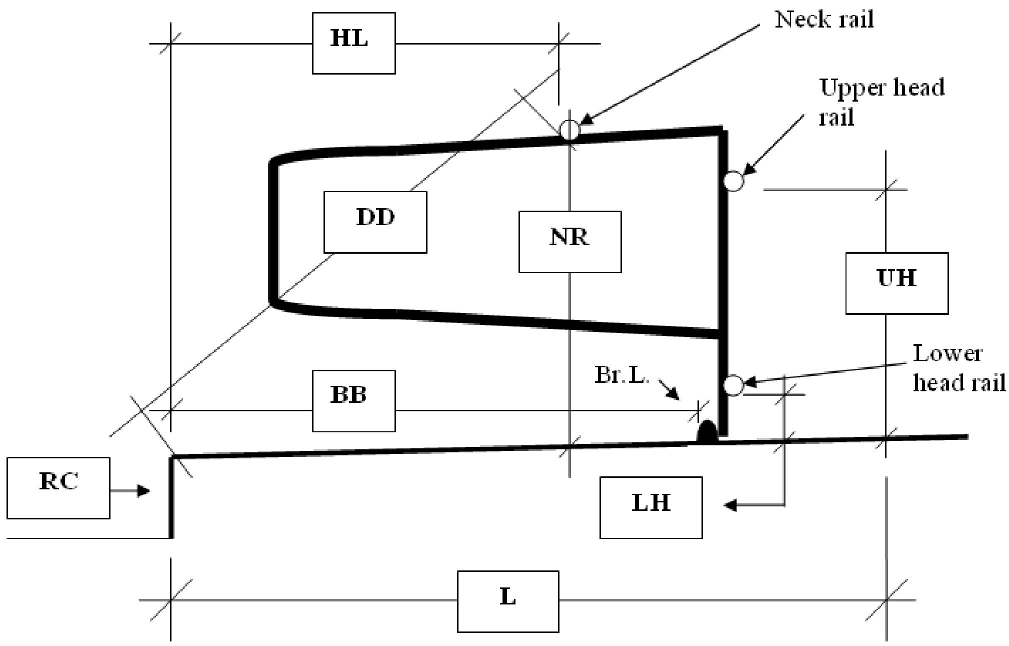

Figure 3. *Free stall design and the components of a free stall. Br.L. = Brisket locator, HL = Horizontal distance for neck rail, DD = Diagonal distance for neck rail, NR = height of neck rail, UH = height of upper head rail, LH = height of lower head rail, BB = Distance from rear curb to brisket locator, RC = height of rear curb, L = total stall length.*

Free stall base

Lying is an important and highly prioritized behaviour in cattle (Albright and Arave, 1997), and adequate rest, at least 12 – 13 h per day (Jensen et al., 2005), is of major importance to the health, welfare and productivity of dairy cows. Optimal free stall design is essential for allowing cows enough time to rest (Tucker et al. (2004b). The lying time is influenced, amongst other factors, by housing and bedding (Krohn and Munksgaard, 1993). Several experiments has shown that dairy cows has a strong preference for resting on soft surfaces (Wander, 1974; Natzke et al., 1982; Irps, 1983; Gebremedhin et al., 1985; Nilsson, 1988; Cermak, 1988; Colam-Ainsworth et al., 1989; Herlin, 1997; Rushen et al., 2001; Manninen et al., 2002; Tucker et al., 2003; Fregonesi et al., 2009b), and there also seem to be a close relationship between softer stall bases and increased lying time (Rushen et al., 2001) and increased stall cleanliness (Herlin, 1997). Reasons for preferring soft floorings is found in improved comfort due to reduced contact pressure to protruding body parts when lying, improved friction when raising (Hansen et al., 1999) but also reduced heat conductivity (Nilsson, 1988; Hansen et al., 1999). A comfortable stall base in a free stall allowing normal lying behaviour is important to ensure that the cows chooses to use the stall for rest, sleep and rumination and also reduces the risk for cows to get lesions or other damages to their body (Rousing et al., 2000; Fulwider et al., 2007; Kielland et al., 2009).

In order to provide a simple and objective method for measuring stall base softness, Nilsson (1988) expressed softness as mm impact of a sphere (diameter = 100 mm) at 2 kN load, a method adapted to a sphere with the approximate diameter of a cow's knee (diameter = 120 mm) by ADAS (Dumelow, 1995) and later applied by others, e.g., Deutsche Landwirtschafts-Gesellschaft (DLG, 2009) in their testing procedures for mats and mattresses (Figure 4). The load of 2 kN is approximately the maximum load at each front knee during raising or lying down movements (Nilsson, 1988; Hansen et al., 1999).

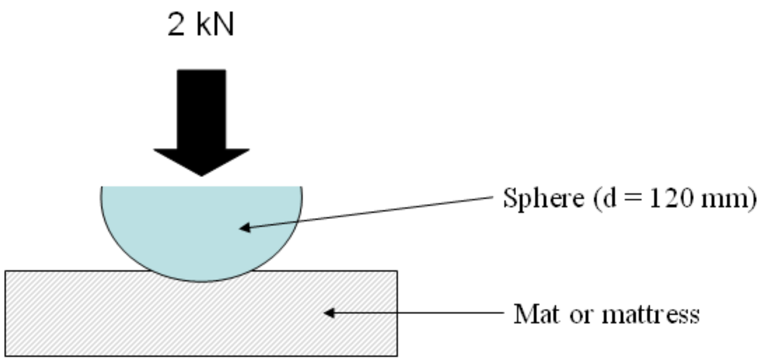

Figure 4. *The softness of mats and mattresses is expressed as mm impact of a sphere (d = 120 mm) at 2 kN load. This situation simulates the situation of a cows' front knee when raising or lying down.*

Recommended softness of stall base is minimum 16 mm impact (Hansen et al., 1999; Anonymous, 2001; Ruud et al., 2005; Norwegian Food Authorities, 2005). Typical products according to these recommendations are multilayer mats or mattresses (Table 1).

Table 1. *Softness of different free stall floorings for dairy cows (with exception of straw or sand-bedded stalls) is measured as mm impact of a sphere (d = 120 mm) at 2 kN load (Nilsson, 1988; Dumelow, 1995; DLG, 2009) and one may categorize products into one of the following classes according to softness.*

Class	**Softness, mm impact[1]**	**Typical product**
Concrete	0	Hard free-stall base made of concrete without any extra cushion
Rubber	1 to 8	Free-stalls equipped with compact rubber mats
Soft mats	9 to 16	Lightweight "comfort mats" or rubber mats with rubber studs underneath them contributing to softness
Multi-layer mats	17 to 24	Multi-layer mats
Mattresses	> 24	Soft mattresses

[1]Minimum softness of a "soft" free stall base in Norway is 16 mm (Norwegian Ministry of Agriculture and Food, 2004; Norwegian Food Autorithies, 2005).

Use of bedding may influence on softness (Wander, 1974; Tucker et al., 2004b) as well as hygiene (Herlin, 1997, Tucker et al., 2004b). Dairy cattle are found to prefer stalls heavily bedded with sawdust compared to stalls with limited amount of sawdust (Wander, 1974), even if the stall base consists of compact rubber mats (Jensen et al., 1988; Manninen et al., 2002; Tucker et al., 2004b; Fregonesi et al., 2007). Lying and standing behaviour is influenced by the amount of saw dust, the number of investigative head swinging behaviour per lying bout was for example found to decrease when the amount of sawdust per stall increased (Tucker et al., 2004b). Bedding is therefore of importance for the cows per se. This was also evident in a study where cows could choose between wet or dry sawdust (Fregonesi et al., 2007). No documentation was found where the bedding softness is measured and expressed in the same way as for mats or mattresses, probably due to difficulties in defining a starting point for each softness measuring cycle and also because bedding in itself is hard to standardize.

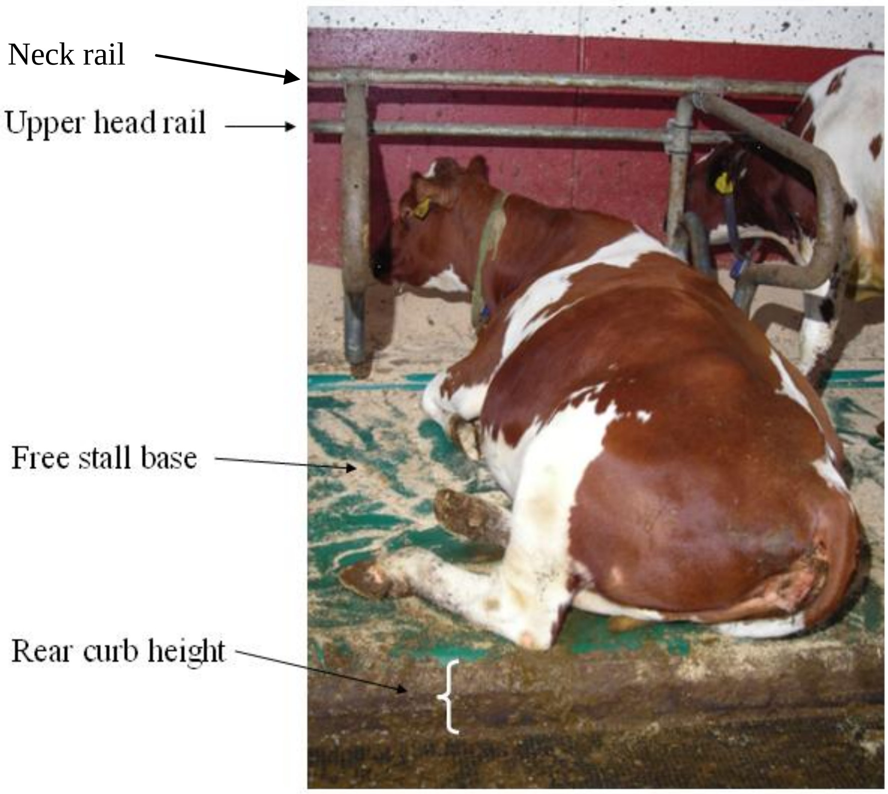

Figure 5. *The stall in the illustration is equipped with neck rail and upper head rail, but is without lower head rail and brisket locator. This cow is lying on a multilayer mat sparingly bedded with sawdust. Rear curb height is approximately 0.25 m.*

Lengthwise space

An optimal free-stall design must allow the cows to unhindered lie down, lie and raise easily (Lidfors, 1989; Anderson, 2008). As defined by Baxter (1984) the cow need space, lengthwise and laterally, equal to the sum of body and dynamic space. The body space equals the space occupied by her body and remains relatively constant for an individual despite activity, whereas dynamic space is the extra space necessary for performing e.g. raising movements. Cows are lunging about 0.6 to 0.8 meter forward during the raising and lying movements (Albright and Arave, 1997; Ceballos et al., 2004), whereas the total distance for getting up on her legs sums up to approximately 3 meters (Ceballos et al., 2004). The dynamic space may be illustrated as a raising envelope (Cermak, 1988; Irish and Merrill, 1986; Ceballos et al., 2004) (Figure 6). The cow will also move the head downwards in a bobbing action during the raising movement to help herself up on the front legs (Anderson, 2008), hence dynamic space should be available also for this bobbing movement. There seemed to be an idea that stalls could be 0.3 to 0.45 m shorter (less dynamic space) if they were equipped with open dividers allowing "side lunging" (Albright and Arave, 1997), however this is in contrast with e.g. McFarland and Graves (1995) arguing for the possibility of the animals to raise straight forward as being natural for them.

Lengthwise restrictions are used to control defecation behaviour to keep stall and cow clean. However, the rail positions will be a compromise between too "large" and too "small". Generally, if rails are restrictive, there may be conflicts between lengthwise restrictions in stall and body and dynamic space, cows may reject to use the stalls (Fregonesi et al., 2009a), changes lying or defecation behaviours or raises in a way not natural for them e.g. with the front end first like a horse (Anonymous, 2001). Otherwise, with "spacious" restrictions the risk for being contaminated increases (Veissier et al., 2004; Tucker et al., 2005).

Head and neck rails as well as the brisket locator are defining accessible body and dynamic space in a free stall, and should hence become more focus compared to the length of the free stall base when discussing functional stall design.

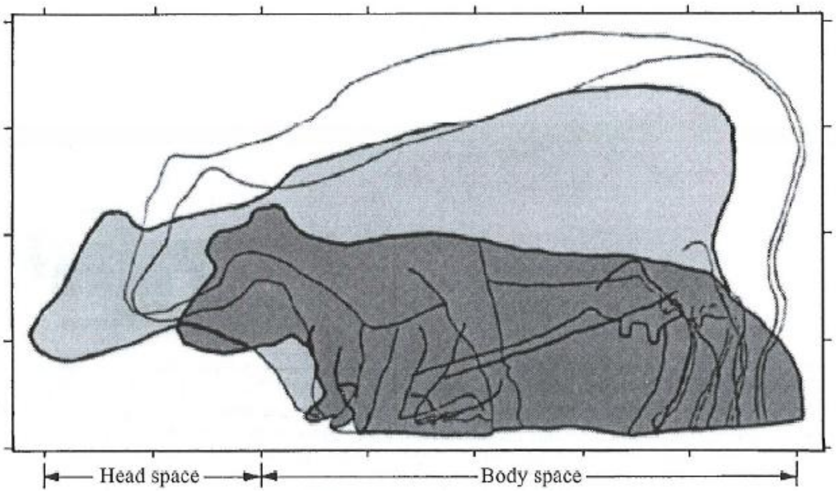

Figure 6. ***The “raising envelope” illustrates the body and dynamic space needed by the cow in different stages of the raising movement (Cermak, 1988).***

The function of the rear curb (Figure 3 and 5), besides partly defining the length of the stall base, is to elevate the free stall base and separate it from the normally wet and dirty floor in the alley in order to improve stall cleanliness (Magnusson et al., 2008). Recommended height of the rear curb (Table 2) is 0.15 to 0.3 m, however the scientific knowledge on rear curb design seems to be scarce.

<u>*Neck rail*</u>. The neck rail is controlling the forward position of the cow before lying down, supposedly leaving some space in front of her accessible for raising later (Anderson, 2008). The main function of the neck rail (Figure 3 and 5) is to prevent animals from defecating in stall through positioning them before lying down (Tucker et al., 2005). A parallel could be made to the electric cow trainer used in tie-stalls. A restrictive position of the neck rail contributes to a cleaner stall through hindering cows in standing too far into the stall when or if defecating (Jarrett, 1986), but it is also found that the time cows are standing with only the front feets on the stall base increases (Fregonesi et al., 2009a), the risk that cows are rising or standing diagonally in stall may increase (Anderson, 2008), cows may get neck lesions (Kielland et al., 2010) and the prevalence of lameness and hoof diseases is increased (Bernardi et al., 2009). Tucker et al. (2005) found 69 % of the cows in a study to soil in the stall even if neck rail was present. Hulsen (2005) recommends looking for shiny metal in stalls as an indicator of frequent contact between cow and stall. The neck rail is usually made of a steel pipeline (diameter 50 to 60 mm), however one may

also utilise flat nylon straps, chains or wood planks. To increase stall comfort, the contact pressure between cow and rails should be kept as low as possible. One could therefore, in addition to location, choose profiles with large diameter, planks with rounded edges or parts with elastic properties (Ruud et al., 2005; Anderson, 2008).

The position of the neck rail is described by these parameters (Figure 3):
Height; the shortest distance from free stall base to the neck rail.
Horizontal distance; the horizontal distance from neck rail to an imaginary point positioned vertically above the rear curb.
Diagonal distance; the shortest distance from rear curb and diagonally up to the neck rail.
Recommended height and horizontal distance for neck rail used for 550 to 600 kg cows is 1.07 to 1.17 m and 1.58 to 1.70 m respectively (Table 2).

Upper and lower head rails (Figure 3). The main function of the head rails is to prevent cows from walking through or to stand too far forward into the stall to keep the stall clean (Anderson, 2008). In some stall designs, head rails also play a constructive role. The head rails define dynamic space accessible for the cows lengthwise in the stall when raising. Possible signs of improper function may be abnormal raising behaviour, defecation or stall refusal (Anderson, 2008). The head rails are normally made of a steel pipeline with diameter 50 to 60 mm, however other designs or materials may also be utilized.
The location of head rails are described by the height as the shortest distance from free stall base to the lower side of the rails. Recommended height above stall base for lower and upper head rails are 0 to 0.2 m and 0.73 to 1.02 m respectively (Table 2). The horizontal distance of head rails is normally the same as the length of the stall base, however, in some stall designs these distances are different. Studies on head rails exists (e.g. Veissier et al., 2004; O'Connell et al., 1989; 1992), but despite their huge impact on for example raising movements, it has received remarkably little attention.

Brisket locator (Figure 6). The function of the brisket locator, if used, is to restrict the most forward position of cows when lying in stall (Tucker et al., 2005; Anderson, 2008). This is important as the neck rail is not influencing on defecation behaviours when lying, of course except positioning the cow before lying down. Tucker et al. (2006) found that the brisket locator improved stall cleanliness but reduced lying time. However, the brisket board used in that study was higher than recommended. Brisket locator is recommended not to be higher than approximately 0.1 m (Table 2) as cows are bobbing their head as low as 0.1 to 0.3 m above ground during raising (Ceballos et al., 2004). Originally, the brisket locator was designed as a plank or a board, known as a brisket board, but in newer stall designs it is often made of plastic or other semi-flexible materials or as a rounded profile. Position of the brisket locator is described as the brisket locator distance; the shortest distance from brisket locator to the rear curb of the stall, and brisket locator height; the height from stall base to the top of the brisket locator measured at the cow side of the locator (Figure 3 and 7).

Figure 7. *Neck rail, cantilever stall divider and brisket locator in a free stall.*

Lateral space (stall dividers)

The lateral space in a free stall, and thereby the possibility for the cow to move laterally, is defined by the stall dividers. Without dividers, there will only be an open lying area without possibilities for controlling defecation behaviours. Fregonesi et al. (2009b) found cows to prefer open bedded-pack solutions without restrictions before free stalls, in fact questioning the use of partitions at all. However, the differences were not very strong.

Lateral space in a free stall is the distance between stall dividers, also defined as the width of the stall. The function of the free-stall divider (Figure 3 and 7) is to separate cows while lying, define the lateral place for lying, guide the cows when entering or exiting the stalls, protect them while resting (Gamroth and Stokes, 1999) and also prevent them from turning in stall (Irish and Merrill, 1986) in that way controlling defecation behaviour and cleanliness. The stall dividers also represent a physical division reducing aggressive interactions at the same time as closeness between animals is allowed. These functions should be performed without causing injury or entrapment of the cow, at the same time as space needed for normal lying down and raising behaviour should be available (Fregonesi et al., 2009a). A narrow stall will be a risk factor regarding e.g. lesions (Kielland et al., 2009) and lying behaviour (Tucker et al., 2004a) whereas wider stalls are found to be associated with dirty stalls and cows (Tucker et al., 2004a). The stall width therefore has to be adapted to the size of the cow (CIGR, 1994; Anderson, 2008). Recommended stall width (between dividers) is 1.03 to 1.14 m (Table 2).

Today, the design of stall dividers is normally a cantilever stall partition, however additional profiles attached directly on the stall base are also tested with good results (Wandel and Jungbluth, 1997). As previously discussed; if the forward lunge movement of the cow is obstructed in some way, it is important for the cow to have the possibility to side lunge when raising (“open dividers”) (CIGR, 1994). However, it is argued to be an option compared to straight forward raising (McFarland and Graves, 1995; Anderson, 2008). In a side lunging situation the upper part of the divider will be a kind of neck rail. General recommendations is that it should be positioned approximately at the height of the neck rail (Andersson, 2008), whereas the lower part of the divider rail should allow some space for leg and udder (CIGR, 1994; Albright and Arave, 1997). O’Connell et al. (1992) compared an enclosed type of divider (“Newton rigg”) to more open cantilever dividers (“Dutch comfort”) and found the stall occupancy rate to increase with the latter. Hence, stall divider design is found to affect the cows and is also of importance to the cows.

Choosing yielding rails or free stall components are probably positive due to a lower contact pressure to the body of the cow with regard to lesions (Blom et al., 1984). In a study with vertically positioned elastic partitions used in tie-stalls, Aland et al. (2009) found the partitions to influence on stall cleanliness and lying position. Wandel and Jungbluth (1997) utilized a free swinging horizontal wooden plank as free stall dividers and found this construction to be effective and gentle to the animals, but no effects on lying time were found. Gwynn et al. (1991) found dividers with a rope replacing a fixed bar to be more popular than the original fixed version. Scientific knowledge on effects of free stall divider design on e.g. lying behavior, cleanliness, and preference is scarce, and the development of free-stall dividers seems to be mainly industry driven.

Table 2. *Recommended free-stall design for dairy cattle. All measures in meter.*

	NFA [1] (550 kg)	Norw. rec. [2] (570 kg)	CIGR [3] (550 kg)	Anderson [4] 1st lact. (700 kg)	McFarland [5] (550 kg)
Free-stall length – wall	2.40	2.40 – 2.60	2.39	2.74 – 3.04	2.34 – 2.49
Free-stall length – free	2.10	2.30 – 2.50	2.06	2.43 – 2.74	2.03 – 2.19
Width	1.14[6]	1.14[6]	1.12	1.21[6]	1.03 – 1.09[6]
Neck rail - height	-	1.10 – 1.15	"Not to low"	1.22	1.07 – 1.17
Neck rail - diagonal length	-	-	-	-	-
Neck rail - horizontal length	-	1.60 – 1.70	-	1.73	1.58 – 1.63
Upper head rail height	-	0.80 – 0.90	Min 0.73	0.86 – 1.02	-
Lower head rail height	-	0 – 0.20	-	Absent	-
Brisket board height	-	0.07 – 0.10	-	0.10	0.10 – 0.15
Brisket board length	-	1.70 – 1.80	1.63	1.78	1.58 – 1.63
Rear curb height	0.15 – 0.25	0.20 – 0.30	0.15 – 0.20	0.20	0.30

[1] From guidelines to Norwegian regulations on keeping cattle (2005).

[2] Ruud et al. (2005).

[3] CIGR (1994).

[4] Anderson (2008).

[5] McFarland (2003).

[6] Centre to centre measure converted to inside measure by subtracting 60 mm for thickness of the pipeline.

Aim of the thesis

The overall aim of this thesis was to describe free stall design and to evaluate effects of free stall design on cleanliness, milk yield, health and behaviour.

More specific issues addressed in the papers included in this thesis are:

- To describe free-stall design, free stall and cow cleanliness as found in Norwegian free stalled dairy herds
- To investigate the associations between free-stall base softness and milk yield, incidence of clinical mastitis, teat lesions, and removal of cows.
- To evaluate effects of free stall design on free-stall cleanliness
- To examine risk factors for dirty cows related to free stall design and housing.
- To investigate effects of stall divider design on lying behaviour and also the preferences of the cows regarding stalls with fixed or flexible stall dividers.

Summary of materials and methods

Paper I

Paper I is based on a questionnaire that was sent to 1,923 dairy farms presumed to have a free-stall housing system during the winter 2004 - 05. The farmers were asked for information regarding the free stall base, e.g., the product name or brand of their mats or mattresses, the year of installation as well as some housing aspects. A total of 704 farmers responded to the questionnaire. Herds with unknown year of installation of mats or mattresses, with more than one particular kind of free-stall base, with a barn newer than the mats or mattresses, with mats or mattresses older than 1998 (if not concrete), a barn itself older than 1980, and mats and mattresses installed in 2005 were excluded. Herds not registered in the Norwegian Dairy Herd Recording System (NDHRS) were also excluded. The final dataset consisted of 363 herds. With information about the brand name of free-stall base available in the questionnaire, the herds were categorized after softness of free stall base according to test reports from Deutsche Landwirtscahftliche Gesellschaft (DLG, 2009). Softness is expressed in the test reports as mm impact of a sphere (d = 120 mm) at 2 kN load. Stall base softness for each farm was categorized into one of the following five classes of softness; 1) softness 0 mm - typically concrete, 2) softness from 1 to 8 mm – typically compact rubber mats, 3) softness from 9 to 16 mm – typically soft, lightweight mats, 4) softness from 17 to 24 mm – typically multilayer mats, or 5) softness more than 24 mm – typically mattresses. Milk yield and health data from each individual cow in the study herds were extracted from the NDHRS database (Østerås et al, 2007) for the year after installation of mats or mattresses. The following data were collected; test-day, kg milk on test-day, kg concentrate fed on test-day, information about disease on test-day, parity, calving day, day of removal from the herd, and all disease treatments including day of treatment. After exclusion of invalid contributions, the dataset for milk yield consisted of 29,326 lactations for 17,528 different cows distributed over 363 herds in Norway. Lactation curves were estimated as modified Wood’s lactation curves using test day data and mixed models with repeated measurements, adjusting for days in milk (DIM), parity, and softness of free-stall flooring. The milk yield data were fit in a mixed model using the Proc Mixed procedure in SAS (SAS version 9.1. from SAS Institute Inc., Cary, NC, USA) with test-day milk yield as the dependent variable. DIM, lnDIM, if the cow was diseased on the test-day, free-stall base softness class, test-day year and test-day month were used as fixed variables. The final model also included interaction between DIM, lnDIM and softness class. The mixed models were run with repeated measurements applying autoregressive correlation type 1 matrix AR(1) and were fitted separately for parity 1, 2, 3 and > 3. All recordings for clinical mastitis, teat lesions and removal were merged with the information about stall base softness from each farm on lactation level and used in a survival analysis. The health data were analysed using the survival analysis Proc Lifetest and Proc Phreg in SAS (SAS version 9.1. from SAS Institute Inc., Cary, NC, USA). Data observations were censored at end of lactation, next calving or at 305 DIM if no calving or removal. Softness classes 1, 2, 3, 4 and 5 were included as covariates and adjusted for parity 1, 2, 3 and > 3 and recording year as fixed effects. The survival analyses were run for the period from 15 days before calving until a primary case of disease or removal, as well as the period from the primary case of clinical mastitis until a secondary case of clinical mastitis was run in separate models. Separate models were made for clinical mastitis, teat lesions and removal. The estimates were adjusted for year of calving if significant.

Paper II and III

The material used in Paper II and III were part of a larger descriptive and cross-sectional project on freestall housing called “Freestall barns for dairy cows” in which the selection of herds concerned the entire project. From a questionnaire to all dairy consultants in Norway, a list was obtained of 2,400 dairy herds that were presumed to be housed in free stalls. These farmers received a questionnaire covering several aspects of their freestall housing system. To be included in the final study, the farmers had to fulfil our inclusion criteria; volunteer to participate, barns built 1995 to 2005, and herd size > 20 standardized cow-years based on the year 2005. As we expect some housing systems to be common in the future, all dairy farms with robotic milking, with solid concrete floors or solid rubber floors in the alleys were included. Herds on slatted floors fulfilling the inclusion criteria were included only if they were located in the same municipality as farms with robotic milking or solid floors as mentioned above. The total material used in Paper II and III consisted of 232 free-stalled dairy herds located all over Norway. During the period from September 2006 until May 2007 all the herds were visited once by one of five trained observers recording stall and cow cleanliness and other variables not reported in present thesis. *Stall cleanliness* (Paper II) and use of bedding was assessed in 7 different sectors of the free stall (Figure 8) in 15 random selected free-stalls in each of the 232 dairy herds. Of these, 8 herds were excluded from the statistical analyses due to stalls recently being cleaned out despite instructions not to do so. The observers also recorded the position of head and neck rails as well as stall width and location of a possible brisket board. The cleanliness of each sector was scored using a five grade scale reflecting the degree of contamination of each section. Two types of contamination were registered; faeces dropped on stall base (FAECES) and wet footprints (FOOT). Free-stall base was classified according to softness as; 1) concrete, 2) solid rubber mats, 3) soft mats and mattresses and 4) mixed. Softness, expressed as millimetres of impact of a sphere (d = 120 mm) at 2 kN load, was not measured on-farm in the present study, but the DLG test reports were used as a guideline for allocating the free-stall bases into the categories. As the contamination of the stalls was mainly located in the rear sectors (E to G), the statistical models were made on the basis of these. The models were constructed at stall sector level using proc genmod (SAS version 9.1. from SAS Institute Inc., Cary, NC, USA) with log link function, binomial distribution with dirty (cleanliness score one to four) or not dirty (cleanliness score 0) as dependent variable. Correlation within stall and within herd was taken care of by including stall nested within herd as a random effect (*repeated subject= herd/ logor=nest1 subcluster stall).*

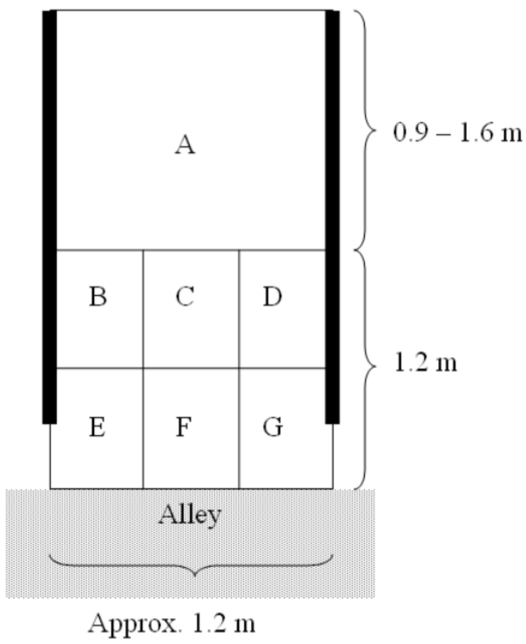

Figure 8. *The free-stall base was divided into 7 sectors (A to G) where cleanliness was scored individually using a five grade scale referring to the degree of contamination in each sector.*

Cow cleanliness (Paper III), management related (e.g. ventilation and use of sawdust in stalls) and housing related variables (e.g. free-stall design and number of cows per stall) were recorded in the same 232 free-stalled dairy herds as mentioned above. According to their unique ID number, 10 cows on each farm, in total 2335 cows, were randomly chosen and subjected to cleanliness observations using a 4 grade scale (Figure 9) adapted from Schreiner and Ruegg (2003); 1) clean, 2) some dirt, 3) dirty, or 4) very dirty with caked-on dirt. Udder, belly, leg, thigh and rear part of the body were assessed separately for cleanliness. Only risk factors for dirty thighs were analyzed in a full statistical model and reported in Paper III. The final model was constructed with thigh as the statistical unit using proc genmod (SAS version 9.1. from SAS Institute Inc.), with log link function, binomial distribution with clean (cleanliness score 1) or dirty (cleanliness score 2 to 4) as dependent variables. The regression was performed using alternating logistic regression, and taking care of the correlated and repeated observation of thigh cleanliness within herd and cow by including cow as a subcluster nested within herd as subject in the repeated effect statement applying the logor option. Clustering effect due to observer was checked by testing observer as a random effect in the model.

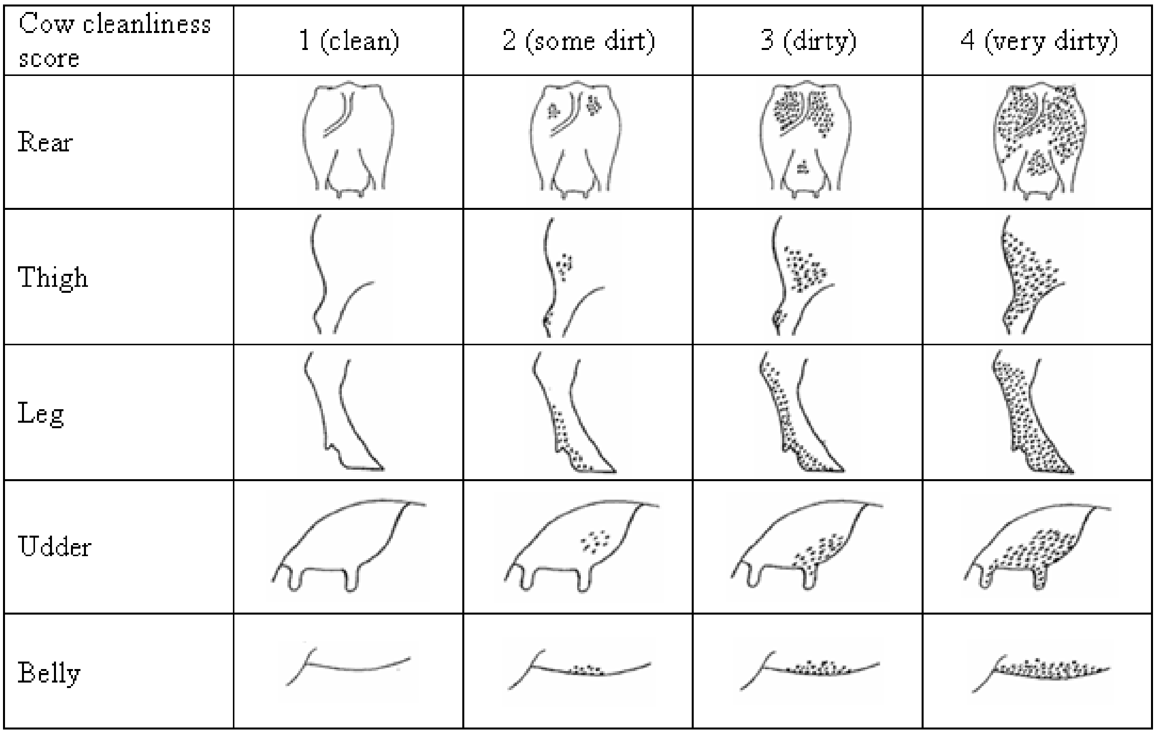

Figure 9. *Scheme used for assessing cow cleanliness. Adapted after Schreiner and Ruegg (2003).*

Paper IV

In a controlled study using a cross-over design, 16 dry dairy cows were single housed for totally nine days in pens with two free-stalls, one with standard commercial fixed cantilever dividers (FIXED; CC1800™ from DeLaval™, Tumba, Sweden) and one with more experimental flexible stall dividers made of fibre glass (d = 40 mm) with a PVC sleeve outside (FLEX; Freedom stall™ from J&L™, USA) (Figure 10). The stall design in present study was based on the findings that were associated with improved stall and cow cleanliness in Papers II and III. The cows were first restricted to one of the stalls (4 d), then to the other type of stall (4 d) and finally they were given access to both stalls in a preference test (1 d). Lying time, number and duration of lying bouts and stall cleanliness were video recorded the last 48 h of each restriction period. When analyzing the video tapes for behaviour, an observation interval of 10 minutes were used. In the preference test, the first-choice and preference were observed and recorded. One cow was excluded because of never using the stalls, hence the dataset used in the paper consisted of n = 15 cows.

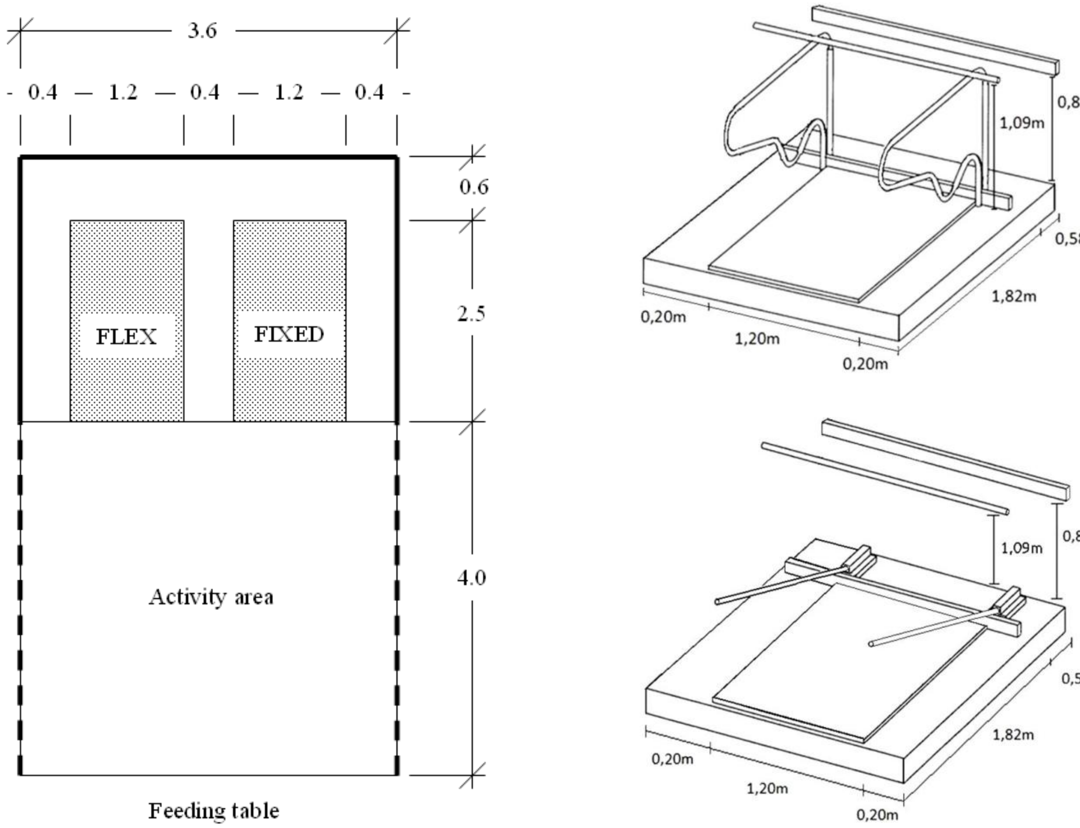

Figure 10. *The study cows were single housed in experimental pens (left) with one free stall with flexible stall dividers (bottom right) and one stall with fixed, looped steel pipeline dividers (top right).*

Summary of results

Paper I

Herds using soft free-stall bases were significantly associated with higher milk yield and a lower incidence of clinical mastitis, teat lesions, and removal of cows compared to herds using harder stall surfaces. Cows on concrete free-stall bases were in average associated with a milk yield of 6,727 ± 146 kg of milk from 5 to 305 days in milk (DIM). In comparison, rubber mats showed a decrease of 0.3 %, soft mats increased 2.4 %, multi-layer mats increased 4.5 % and mattresses resulted in an increase of 3.9 %. Compared to concrete, the hazard ratio (HR) of clinical mastitis was lower on rubber, multi-layer mats and mattresses; HR = 0.89, 0.85 and 0.80 respectively (95 % confidence intervals shown in paper I). Compared to concrete flooring, the hazard ratio of teat lesions was lower on rubber, soft mats, multi-layer mats and mattresses; HR = 0.41, 0.33, 0.12, and 0.47 respectively. The hazard ratio of removal of cows was lower on mattresses compared to concrete, rubber, soft mats and multi-layer mats with HR = 0.90, 0.88, 0.86, and 0.85 respectively.

Paper II

Associations between stall cleanliness, and stall width and length were found. Further, stall design associated with an open front in free stalls was found to be of importance for stall cleanliness. Mean stall base length in the selected herds was 2.39 (± 0.21) m (mean ± SD) when located against wall and 2.23 (± 0.11) m in a double row. Mean height of neck rail was 1.07 (± 0.05) m, upper head rail 0.90 (± 0.15) m and lower head rail 0.37 (± 0.18) m. Mean position of brisket locator was 1.83 (± 0.14) m from rear curb, and mean height was 0.10 (± 0.05) m. Contamination was mainly observed in the three rear sectors of the stalls. Faeces (cow pats) were mostly found in the lateral sectors whereas "wet foot prints" were found in the middle sector. Sawdust was the most common type of bedding material recorded for 85.3 % of the herds. The mean amount of bedding recorded in the rear 1.2 m of the stalls was 0.6 (± 1.2) L per stall, whereas the mean amount of bedding material in stalls with sawdust was 0.8 (± 1.5) L. Bedding was not used at all for 13.4 % of the herds and less than 0.2 L of bedding was recorded in 44.6 % of the stalls. Hence, the amount of bedding was so low that no effects on softness could be expected.

The following variables were found to be risk factors regarding FAECES contamination in stall:

- Not using bedding (odds ratio (OR) = 1.99) or using 0.2 to 1.0 L of bedding (OR = 1.42) versus using > 1.0 L (OR = 1.00)
- Brisket locator distance > 1.83 m (OR = 1.97) versus ≤ 1.83 m (OR = 1.00)
- Diagonal stall length > 1.96 m (OR = 1.00) versus ≤ 1.96 m (OR = 0.60)
- Presence of lower head rail (OR = 1.00) versus absence (OR = 0.60)
- Stall length ≥ 2.45 m (OR = 1.00) versus 2.30 to 2.45 m (OR = 0.74) or < 2.30 m (OR = 0.66)
- Upper head rail ≤ 0.70 m (OR = 1.48) m versus > 0.70 m (OR = 1.00)
- Stall width ≤ 1.13 m (OR = 1.33) versus > 1.13 m (OR = 1.00)

The following variables were found to be risk factors regarding FOOT contamination in stall:

- Amount of bedding ≤ 0.5 L (OR = 5.61) versus > 0.5 L (OR = 1.00)
- Soft stall base with < 0.5 L of bedding (see Paper II for illustration of the interaction between amount of saw dust and softness)
- Brisket locator height ≤ 0.1 m (OR = 0.61) versus > 0.10 m (OR = 1.00)
- Upper head rail ≤ 1.0 m (OR = 1.47) versus > 1.0 m (OR = 1.00)
- Rubber mats (OR = 4.19), mattresses (OR = 3.79) and mix (OR = 3.06) versus concrete stall base (OR = 1.00)
- Stall width > 1.13 m (OR = 1.00) versus ≤ 1.13 m (OR = 0.78)

Paper III

The present study showed that the cows were relatively clean on udder and belly, dirtier on thigh and the rear part of the body and most dirty on the legs. Dirtiness of thigh was the site most correlated to dirtiness of all the other sites on the body recorded for cleanliness.

Associations were found between thigh cleanliness and housing and management related variables. Freestalls with upper head rails located < 0.86 m above stall base should be avoided, however, focus is also needed on indoor climate and manure consistency to obtain clean cows.

The following variables were found to be risk factors for dirty thighs on the cows:

- More cows per free stall was associated with dirtier thighs (OR = 3.45)
- no use of sawdust as bedding (OR = 3.24) versus use of bedding (OR = 1.00)
- Upper head rail positioned 0.52 - 0.75 m (OR = 2.13) above stall floor and a position from 0.76 to 0.85 m (OR = 1.42$^{\text{tendency}}$) versus > 0.85 m (OR = 1.00)
- More fluid manure consistency was associated with dirtier thighs compared to lower manure consistency score (OR = 1.66)
- Less tame cows; tameness class 2 (OR = 1.24) versus class 1 (OR = 1.00)
- The cleanest cows were found in the temperature zone between 10 and 15 °C (calculated in a spread sheet). With indoor temperature > 15 °C the dirtiness of thighs increased with increasing temperature (OR = 1.01 to 1.25)
- Higher relative air humidity (OR = 1.03) was associated with dirtier thighs compared to lower relative air humidity

Paper IV

No differences in total lying time, lying positions, stall cleanliness or time spent standing with two or four feets in stall (P > 0.15) were found when comparing flexible and fixed cantilever stall dividers. However, a majority of the cows preferred stalls with flexible dividers (P < 0.02) before fixed dividers in the preference test. In both treatments, the lying time was relatively high, 13.5 to 14 hours (SD in the paper). More than 95 % of the lying time, cows were lying with some part of the body laterally to the side of the stall border, and likewise, the cows spent more than 75 % of the lying time lying with tail root behind the rear curb of the stall. The percentage of cows standing with all 4 hooves in stall out of total standing time in stall was relatively low. The stalls remained remarkably clean during the experiment, only two cow pats were identified in stall during the study period.

General discussion

Main results from present study were the description of free stall design and level of cleanliness as found in Norwegian herds, the importance of soft stall flooring on milk yield and udder health, the importance of bedding and the effect of housing and management parameters on cleanliness, as well as the test of flexible partitions. Until the conduction of present study, knowledge about the use of group housing and free stalls was limited on such a scale and geographic spread in Norway.

A considerably variation in stall design and further in cow and stall cleanliness were found, illustrating that there is a large potential for improvements in stall and housing design as well as the management routines on the farms. In larger herds where labour input per cow normally is lower compared to smaller herds (Næss, 2010), one is even more dependent on stall and housing design working properly to achieve acceptable welfare and hygiene. Random effect of stall was higher than random effect of herd (Paper II), meaning that focusing on stall design before management routines may prove to be the most effective place to start the struggle for cleaner and more optimal stalls.

Free-stall design

In general, most stall design traits were found to be in accordance with or some what smaller compared to Norwegian regulations and guidelines. However, details on position of head and neck rails are not pointed out there (Norwegian Ministry of Agriculture and Food, 2004; Norwegian Food Authorities, 2005). In present study, mean height of upper and lower head rails were 0.90 and 0.37 m respectively (Paper II). The position of the upper head rail is in accordance with Norwegian recommendations (Ruud et al., 2005), Canadian recommendations (borderline) (Anderson, 2008), international recommendations (CIGR, 1994) and also seems to follow conclusions of Veissier et al. (2004) to use a position of the head rails that leaves space for the head of the cow. Mean position of the lower head rail (Paper II) is however in conflict with the latter statement, and is also higher than Norwegian recommendations (Ruud et al., 2005) recommending a position < 0.2 m above stall base. Anderson (2008) recommends absence of a lower head rail.

Neck rail height was 1.07 m, which is lower compared to Norwegian, Canadian and US recommendations (Ruud et al., 2005; Anderson, 2008; McFarland, 2003). Horizontal and diagonal neck rail distances were 1.59 m and 1.92 m respectively, which is also somewhat short compared to the same sources (Table 3).

Brisket locator is the last part of stall components defining parts of the stall front framework. Mean height, if installed, was 0.10 m whereas the horizontal distance to rear curb was 1.83 m. The height of the brisket locator is in accordance to recommendations (CIGR, 1994; McFarland, 2003; Ruud et al., 2005; Anderson, 2008) whereas the distance is longer compared to the same recommendations.

Head rails, neck rail and brisket locator are important parts of the free stall construction, but also stall length in itself has to be taken into consideration (Tucker et al., 2004a). In most farms investigated in Paper II and III, mean free-stall length against a wall (2.39 m) was in accordance with Norwegian regulations (Norwegian Ministry of Agriculture and Food, 2004; Norwegian Food Authorities, 2005), recent US recommendations (McFarland, 2003) and international recommendations (CIGR, 1994), but shorter than recommended by Anderson (2008) and in the lower end of recommendations from the Norwegian Cattle Health Services (Ruud et al., 2005). The free-stall length in a double row was 2.23 m which is complying with Norwegian regulations (Norwegian Ministry of Agriculture and Food, 2004; Norwegian Food Authorities, 2005), international recommendations (CIGR, 1994), and US recommendations (McFarland, 2003), but is shorter than recommended by Anderson (2008) and Ruud et al. (2005).

Most stall dividers in present study were cantilever dividers (Ruud, unpublished data), and mean width of stalls in present study, measured between the dividers, was found to be 1.14 m which is in accordance with Norwegian regulations (Norwegian Ministry of Agriculture and Food, 2004; Norwegian Food Authorities, 2005), Norwegian recommendations (Ruud et al., 2005) and CIGR (1994). There seem to be a smaller discrepancy compared to US recommendations (McFarland, 2003) recommending stall width approximately 0.1 m narrower than e.g. Norwegian regulations, whereas Anderson (2008) are recommending somewhat wider stalls for 700 kg Holstein cows. The variation in stall width was remarkably small (Paper II), however is probably explained by animal welfare regulations.

During the winter 2004/ 05 the distribution of concrete, rubber and soft floorings amongst study herds was 30.9, 47.6 and 16.8 % respectively (Paper I), whereas two years later the distribution was 3.1, 50.9 and 37.1 % (Paper II). The large shift from concrete and rubber to rubber and soft mats may seem strange, but meantime (from January 2006) soft mats became mandatory due to animal welfare regulations (Norwegian Ministry of Agriculture and Food, 2004; Norwegian Food Authorities, 2005) and the change may be explained by farmers with concrete stall bases covering these with soft mats, whereas rubber mats continued in use. The distribution of stall base type is however dynamic and changing and one may expect an even higher percentage of softer types to day.

Free stall and cow cleanliness

As an overall observation the stalls were relatively clean, and as expected the rear sectors were the dirtiest as also found by Gygax et al. (2005) (Paper II). The lateral stall sectors were most likely to be contaminated with faeces, whereas the mid-sectors were most likely to be contaminated with wet footprints. Surprisingly few studies have focused on stall cleanliness.

The cows were relatively clean on the udder and belly, dirtier on thigh and the rear part of the body, and dirtiest on the legs (Paper III) as also found in previous studies, whereas levels of contamination were cleaner or comparable (Schreiner and Ruegg, 2003; Veissier et al., 2004; Reneau et al., 2005; Breen et al., 2009). The cluster effect of herd (OR = 7.01) indicates thigh cleanliness to be stronger associated with herd compared to individual properties (Paper III). This is in contrast to other studies indicating herd effect to be of minor importance (Schreiner and Ruegg, 2003; Veissier et al., 2004; Reneau et al., 2005). However, as discussed later in present thesis, several design traits were found to influence on cow cleanliness.

Concrete floored stalls were found to be cleaner than softer surfaces in present study (Paper II), even more so when using sawdust. This is in contrast to Herlin (1997) that found stalls in a herd with mattresses to stay cleaner than stalls with hard rubber mats or concrete floors. Herlin explains, however, that contamination of the stall base is due to cows defecating while lying down or due to dirt being transported into the stall on the claws. Hence, one may speculate if other parameters, for example stall design, are more important to prevent dirt transport into the stalls than stall base. However, stall base softness may facilitate lying or standing behaviour being associated with increased frequency of defecation or contamination through being more used, e.g. the design of the stall is found to influence on time standing in stall (Tucker at al., 2005).

The amount of sawdust was low (Paper II and III: 0.6 ± 1.2 L in average per stall) compared to e.g. Tucker et al. (2009) and Herlin (1997; 1999) investigating effects of amounts of sawdust from 2 kg to 7.5 L per stall respectively. In present study however, the effect of bedding as a part of the total stall softness will be neglectible.
It is also worrying that nearly 45 % of the stalls were recorded without bedding material (Paper II) as use of bedding adds softness to the stall base (Wander, 1974), influences on stall and animal hygiene (Nygaard, 1979; Herlin et al., 1994) and comfort (Tucker et al., 2004a).

Positive effects of bedding on stall cleanliness were found (Paper II), and not using saw dust was found to be a risk factor for dirty thighs with OR = 3.24 compared to stalls where bedding was used (Paper III). Both findings were evident despite a very low amount of bedding being recorded in present study. An interesting finding was that even as little as 0.5 L of sawdust per stall was found to influence on stall cleanliness (Paper II), especially in concrete floored stalls. These findings are in accordance with the review by Tuyttens (2005) and also studies by Herlin (1997), Veissier et al. (2004) and Tucker et al. (2003; 2009) that all found use of bedding to be an important variable in achieving clean stalls and cows. However, using very small amounts of bedding may also be a risk factor regarding lesions (Kielland et al., 2009).

Management factors will also be of major importance to cleanliness, however, is difficult to fully control in field studies. The findings on indoor climate, animal tameness and animal density however, illustrate the importance of management in present study (Paper III).

Effect of free stall base on milk yield, mastitis, teat lesions and removal

Softer mats or mattresses were associated with increased milk yield and decreased incidence of clinical mastitis, teat lesions and removal compared to stalls with concrete floors or compact rubber mats in present study (Paper I). This is a finding often claimed (Haley et al., 1999; Chaplin et al., 2000; Rushen et al., 2001), however not statistically shown in scientific studies known to us.

The link between stall base softness and milk yield is however complex. One association that possibly could explain why milk yield increases on soft stall bases, is the fact that the blood flow to the mammary gland increases by 20 to 25 % during lying compared to when standing for lactating cows (Metcalf et al., 1992; Rulquin and Caudal, 1992), resulting in more metabolic resources to the milk producing cells in the alveolaes and thus increased milk secretion. According to Davis and Collier (1985), amongst other factors, milk secretion is dependent on the magnitude of the blood flow through the udder. Hart et al. (1978 (found in Tucker and Weary, 2001)) suspected conditions that were associated with short lying time to be linked to a decrease in milk production, but no negative effects on milk yield when cows were deprived of lying were found (Munksgaard and Løvendahl, 1993; Munksgaard and Simensen, 1996). Short resting time may, however, influence on HPA-activity (Ladewig and Smidt, 1989) and the activity of the sympathetic nerve system in cows (Müller et al., 1989) further influencing on nutrient availability, nutrient utilization and productive efficiency (Calamari et al., 2009). Resting in stall is normally associated with a calm and less stressful situation for the cows that one may expect to positively influence on milk yield, as long-lasting stress negatively influences on welfare and productivity (Pajor et al., 2000). Softness of stall base is probably influencing more on lying time compared to stall design (Tucker and Weary, 2001), and due to the strong associations to lying time, one may suspect softness of the stall base to be more important to milk yield compared to the design of the free stall framework itself. Another consequence of short overall lying time, and thereby reduced use of the stalls, is more cows spending a larger proportion of their time in the alleys, at the feed bunk, at the drinkers etc. resulting in for example more possible conflict situations between cows (Krawczel et al., 2008). Soft stall surfaces therefore seem important to improve both welfare and productivity of dairy cows.

Another finding from present study was that soft mats and mattresses were associated with decreased incidence of clinical mastitis and teat lesions (Paper I). Such diseases are per se found to reduce milk production (Geishauser et al., 1999). Hence there may also be an indirect link from properties of the stall base via diseases to milk yield. Rajala-Schultz et al. (1999) found that clinical mastitis had a long lasting effect on milk yield and that the drop in milk yield due to the disease varied from 110 to 552 kg dependent on e.g. severity and days in milk, whereas Deluyker et al. (1993) estimated occurrence of clinical mastitis to be associated with a loss in milk yield of 5 %. Further, the cows were not able to reach pre-mastitis milk yield level after a case of clinical mastitis. Somatic cell count, as a sign of present subclinical mastitis, is also associated with reduced milk production, especially in the last part of the lactation (Hortet and Seegers, 1998). Heat loss is also lower from soft surfaces compared to harder surfaces (Nilsson, 1988) protecting the udder from being cooled. No literature was found that demonstrated effects of flooring temperature on milk yield or clinical mastitis, however, Ewbank (1968) found cooler floors to be associated with increased somatic cell count. A reduction of almost 50 % in the somatic cell count in herds with rubber mats compared to concrete floored stalls was found by Østerås and Lund (1988), whereas Valde et al. (1997) found the incidence rate of mastitis to be reduced by 14 % in herds with rubber mats compared to concrete floors. It is also reasonable to think that durable and intact mats are easier to keep clean, indirectly supporting the udder health.

Softer floorings were found to be associated with a decreased risk for teat lesions in present study (Paper I). Teat lesions are painful for the animals and even minor injuries are found to be associated with increased somatic cell count (Geishauser et al., 1999) and a higher incidence of mastitis (Elbers et al., 1998). Hence, all precautions that reduce the risk for teat lesions will positively influence on the incidence rate of mastitis and thus probably on milk yield. Except the studies of Østerås and Lund (1988) and Bendixen et al. (1988) finding a lower incidence of tramped teats in tie-stalls with rubber flooring compared to concrete, documentation on effects of stall base on teat lesions is scarce. An interesting observation is, however, that the incidence rate of cows with teat lesions reported to the Norwegian Dairy Herd Recording System decreased from 2.7 % in 2003 to 1.3 % in 2008 (NCHS, 2004 to 2009). During this period, “teat lesion” was the diagnosis with the largest decrease in the database. This reduction may be associated with the fact that farmers from January 2006 had to install soft mats and mattresses in free stalls (minimum softness 16 mm impact) due to animal welfare regulations (Norwegian Ministry of Agriculture and Food, 2004; Norwegian Food Authorities, 2005).

Compared to harder surfaces, softer stall bases were associated with a lower risk for non-voluntary removal from the herds (Paper I). Knowledge on effects of stall base softness on removal is scarce and reasons complex, e.g. reproductive disorders, locomotor disorders, as a part of the management, due to teat lesions or other diseases (Beaudeau et al., 2000; Hadley et al., 2006). Teat lesions are often associated with clinical mastitis and further a reduction in milk yield, and sometimes the damage to the teat is of a severity causing removal of that actual cow (Elbers et al., 1998; Geishauser et al., 1999). Soft mats have better slip preventing properties compared to harder stall surfaces (Nilsson, 1988; Nilsson, 1992; Hansen et al., 1999) probably contributing to reducing the prevalence of teat damages etc. in first hand. Thomsen et al. (2007) describes concrete floored stalls to be a risk factor for “looser cows”, cows often ending up in death or culling, and one may also think that a better possibility for e.g. comfortable restitution on soft mats will be positive.

Lengthwise restrictions

Open fronted stall constructions were associated with clean stalls and cows in present study (Paper II, III and IV). This allegation is based on the findings that rails and restrictions located between 0.1 and 1.0 m above the stall base were found to be associated with dirty stalls or cows (Paper II, III and IV).

Low positions of the upper head rail were associated with an increased risk for dirty stalls (Paper II) and thighs, and then also dirty cows through high correlation to other body parts (Paper III). Positions closer than 0.7 m to the stall base were associated with nearly 50 % increased risk for the stall to be contaminated with faeces compared to head rail positions above 0.7 m, whereas positions up to 1.0 m was found to be positive regarding wet foot prints in the stall (Paper II). Upper head rail positions from 0.52 to 0.75 m above stall base were associated with increased risk for dirty cows compared to a position above 0.85 m and also positions from 0.76 to 0.85 m ($P = 0.085^{NS}$) seem less preferable (Paper III).
The findings from present study also clearly demonstrated that clean stalls (regarding faeces) were associated with absence of the lower head rail (Paper II). Mean height of the lower head rail was 0.37 m and it was absent in 51.3 % of the herds.
Knowledge on effects of position of head rails are scarce. Some sources, like Veissier et al. (2004), found positive effects of head rail on cleanliness in a survey, if it was high enough to leave space for the head of the animal. However, no exact location is discussed. Stalls with a less restrictive position of the neck rail, meaning more than 1.96 m measured diagonally from the rear curb, was found to have a higher risk for being dirty compared to more restrictive positions. This association is probably a “cow trainer” effect where the neck rail is reminding the cows to step backwards when defecating, and is in accordance with findings of Tucker et al. (2005) demonstrating that there is a risk for the stall to be contaminated if the neck rail is positioned to far forward in the stall. The influence of neck rail position on the accessible dynamic space during raising is probably of less importance

compared to the head rails as the main purpose of the neck rail is to control defecation behaviours by positioning the cow before she is lying down (Tucker et al., 2005).
No differences between treatments were found in stall cleanliness or time standing either with front hooves, all four hooves or in total time standing in stall (Paper IV), however, compared to Tucker et al. (2005) the proportion of time standing with all 4 hooves in stall was relatively low, indicating, if only taking stall standing behaviour into consideration, that the neck rail position used in Paper IV may be somewhat restrictive.

The brisket locator is defining the lower part of the stall front “frame”. In present study, a brisket locator higher than 0.1 m was associated with dirtier stalls, possibly because it then interferes with the cow during the raising movement. Ceballos et al. (2004) found that cows often moves the head in a height 0.1 to 0.3 m above floor when lying down. Cleanest stalls in Paper II were associated with a brisket locator positioned ≤ 1.83 m from rear curb. Tucker et al. (2006) found use of a brisket locator to improve stall cleanliness as cows also are hindered in creeping forward during lying.

The size of the free stall base, expressed as length and width, is an important parameter in stall design as it influences on the possibility of the cow to stand or lie in the stall. In Paper II an association was found between stall cleanliness (regarding manure following the claws into the stalls) and stall base length. However, the odds ratio for dirty stalls was relatively low. A possible explanation for that may be that some part of the total stall length is not fully available for the animals due to the position of the head and neck rails or brisket locator.

It is interesting to notice that the stalls investigated in paper IV were remarkably clean, as the experimental stall design was based on the “clean-stall” and “clean-cow” studies from Paper II and III. Rail positions typically located as to conflict with the normal lying and raising movements of the cow were associated with dirty stalls and cows. The possibility for performing normal raising behaviour hence seem to be of major importance for obtaining clean stalls and clean cows. Opposite, no discrepancy was found between stalls with head rails allowing normal lying and raising movements and clean stalls and cows. It therefore seems like there is no contradiction between clean stalls and more open-fronted stalls indicating a close link between stall design, cleanliness and cow behaviour (movements); if the demands of the cows for unhindered raising is not satisfied, which may indicate that the cows are actually stressed by using stalls with limited dynamic space, she will defecate more frequent or in other sequences of the raising movement. This is in opposition to the idea that more restrictive positions of rails are positive for cleanliness (e.g. Tucker et al., 2005), one may also think that dirty stalls and cows in fact is the consequence of limited dynamic space in the free stall. Defecation behaviours of cattle are investigated, e.g. describing less frequent defecation and urination during lying compared to milking and feeding periods (Aland et al., 2002), however knowledge on effects of improper stall design directly on defecational behaviour is scarce. There are, however, observations that stressed cows, for example due to new milking procedures, will defecate and urinate more frequent (Kilgour, 1975). Hence, the result may be increased contamination, reduced stall preference or increase stall refusal rate (Kjæstad and Myren, 2001). These findings should however be controlled in a follow-up behavioural study.

Restrictive positions of the head and neck rails, however allowing cows to stand with all four feets on the stall base (Tucker and Weary, 2001; Fregonesi et al., 2009a) have been used in the belief that it would improve stall cleanliness by forcing the dairy cows to defecate outside the stall base (Tucker et al., 2005). This means that body space alone is taken into consideration. This space is needed for cows to be able to stand on the stall base, however, there is an open question if stalls designed according only to this criteria will offer sufficient dynamic space for the cows to perform normal raising and lying down movements as stated by Cermak (1988) and Lidfors (1989). Dynamic raising space in the lengthwise direction of the cow is approximately 0.6 to 0.8 m (Albright and Arave, 1997; Ceballos et al., 2004; Anderson, 2008). Veissier et al. (2004) suspected head rails to influence on behaviour of cows when standing up, and further on cow cleanliness, because they found that stalls with enclosed fronts were associated with dirtier cows.

In a stall with a less open front, the cows will have to raise e.g. with the head to the side through the partitions or by using the diagonal of the stall as this will be the longest accessible distance in the stall. McFarland and Graves (1995) is however arguing for an optimal stall to be the one allowing normal straight-forward raising movements as being normal for the cows.

Also O’Connell et al. (1992) discusses effects of head rail positions in a comparison between Dutch Comfort and Newton Rigg stalls. That study, however, failed to increase occupancy rate as the Newton Rigg front design were manipulated. The reason was may be that the stalls were short, located directly against a wall and that only the Dutch

Comfort stall gave possibility for lateral space sharing and side lunging through the divider. Hence, the stall design that, in some way or another, offered space for the forward movement of the cow was associated with the most optimal function.

Further, it might be a good idea to more clearly differentiate between head and neck rails and their different objects; what works for one rail will not necessarily work for the other one. The consequence of that idea is that these rails and functions should be considered separately when designing new free stalls.

After performing present study, the impression on a general basis is that there may exist an optimal stall size balancing between the need to restrict defecation behaviours and to allow normal raising movements. This idea may be contradictory to the idea of e.g. Anderson (2008) that the animal should be fully able to rise naturally, including the possibility for them to step forward during the last part of the raising movement.

It is also interesting to see that Major Bramley already in the first pioneer stalls more than 50 years ago used vertical bars in the stall front to provide the animals with sufficient dynamic space (Bramley, 1962). In that way raising space was available all the way from floor to some top rail.

Table 3. *Recommended stall design and "optimal" stall design based on observations on stall and cow cleanliness. All measures in meter.*

	NFA[1] (550 kg)	Norw. rec. [2] (570 kg)	CIGR[3] (550 kg)	Anderson [4] 1st lact. (700 kg)	McFarland[5] (550 kg)	Cleanest stalls in present study
Stall base softness[7]	Min. 16 mm					According to milk yield, udder health and removal: ≥ 16 mm
Free-stall length – wall	2.40	2.40 – 2.60	2.39	2.74 – 3.04	2.34 – 2.49	< 2.45
Free-stall length – free	2.10	2.30 – 2.50	2.06	2.43 – 2.74	2.03 – 2.19	-
Stall width	1.14[6]	1.14[6]	1.12	1.21[6]	1.03 – 1.09[6]	1.13
Neck rail height	-	1.10 – 1.15	"Not to low"	1.22	1.07 – 1.17	-
Neck rail - diagonal length	-	-	-	-	-	< 1.96
Neck rail - horizontal length	-	1.60 – 1.70	-	1.73	1.58 – 1.63	-
Head rail – Upper	-	0.80 – 0.90	Min. 0.73	0.86 – 1.02	-	> 0.70[8] > 1.00[9]
Head rail – lower	-	0 – 0.20	-	Absent	-	Absent
Brisket board height	-	0.07 – 0.10	-	0.10	0.10 – 0.15	≤ 0.10
Brisket board length	-	1.70 – 1.80	1.63	1.78	1.58 – 1.63	≤ 1.83
Rear curb height	0.15 – 0.25	0.20 – 0.30	0.15 – 0.20	0.20	0.30	-

[1] Norwegian Ministry of Agriculture and Food (2004); Norwegian Food Authorities (2005).

[2] Ruud et al. (2005).

[3] CIGR (1994).

[4] Anderson (2008).

[5] McFarland (2003).

[6] Centre to centre measure converted to inside measure by subtracting 60 mm for thickness of the pipeline.

[7] Softness expressed as mm impact of a sphere with d = 120 mm with 2 kN load.

[8] Based on faeces in stall.

[9] Based on wet foot prints in stall.

Lateral restrictions

Stalls equal to or narrower than 1.13 m in width were associated with an increased risk of being contaminated by faeces, whereas stalls equal to or narrower than 1.13 m had a lower risk of being contaminated by wet footprints (Paper II). Lateral and mid-sectors of the free stall were most contaminated by faeces and wet footprints respectively (Paper II). This probably means that when cows are walking into the stalls, they will leave wet footprints of manure transported on the claws from the alley on the stall base. The wider the stall, the larger the area covered with footprints. Gygax et al. (2005) found larger stalls to be more contaminated whereas Magnusson et al. (2008) found an association between the amount of manure in the alley and cow cleanliness. However, knowledge on the direct link between stall width and stall cleanliness due to manure being transported into the stall is scarce.

Faeces (cow pats) in lateral stall sectors may originate from cows defecating when lying in stall or from cows standing in or beside the stalls. Defecation from cows standing in alley is not discussed, as this sort of contamination would not be systematically located in the lateral sections of the stall. Tucker et al. (2005) reported that a large proportion of defecation happened while cows are lying down; however, no information was found regarding the time for defecation. If defecation happens just before or during raising, faeces in lateral stall sectors are possibly linked to eliminative behaviour again related to stall design hindering normal raising movements of the cows. Further research, e.g. the link between limited dynamic space, diagonal use of the stall and defecative behaviour, should preferably be performed as no studies known to us were found.

Some stall designs seem to force the cow to use the diagonal length of the stall to optimize e.g. stall standing comfort and raising movements. If this is the case, then accessible space in a stall will in fact also influence on lateral movements and defecation behaviours in the stall. Tucker et al. (2004a) however, found no connection between stall width and forward lunge space regarding cleanliness confirming this idea. In the same study, it was also found that cows tended to stand for a longer time with only front hooves in narrow stalls. In this way the findings from present study, confirms the findings of Tucker et al. (2004a) that stall width may be a problem to cleanliness if too narrow or too wide. Tucker et al. (2004a) found cows to prefer wide stalls, and also found lying time to be significantly longer in wide stalls. Wide stalls and prolonged lying time may however result in cows lying diagonally and further increases the possibility for stalls to be contaminated due to increased use.

A new type of stall dividers that were flexible and even more open laterally, were compared to standard fixed cantilever dividers in Paper IV. It seems like flexible dividers are providing sufficient guidance for the cows, as flexible and fixed dividers performed equally well. As found by Gwynn et al. (1991) and also Wandel and Jungbluth (1997), the cows in Paper IV preferred dividers with yielding properties. Hence, the cows are indicating that type of stall divider is of importance. The physical contact with the dividers in present study was infrequent (Ruud, unpublished data), indicating that the yielding properties of the flexible dividers may be of minor importance for their choices. Contrary to this, Blom et al. (1984) found cows to touch the partitions in a free stall 100 to 150 times per day, however studying relatively enclosed stalls typical for the 1980ies. The reason for the cows to choose flexible dividers is probably that the flexible stall design was more open in front and to the side of the head of the cow compared to the fixed divider. That will be comparable to the studies of Wandel and Jungbluth (1997). As described in section lengthwise restrictions, there is a need for the cow to move the head and body forwards during raising, and space ahead of the cow is hence needed. O'Connell et al. (1992) expressed that cows may sense space in some way, but knowledge on the preference of total space around the head of the cow is scarce. The study of flexible dividers (Paper IV, based on Paper II and III) again demonstrated that more open stalls is positive regarding cleanliness. Hence, from this study one may hypothesize that the design of stall dividers is of minor importance as long as there is space accessible in the stall for normal lying and raising behavior, meaning an open-fronted construction.

Lastly, it is positive to see that positive findings on cleanliness are pointing in the same direction as the possibility for the cows to perform normal behaviour.

Methodological considerations

As present study was part of a larger project, we selected farms with traits we thought would be found on future farms, e.g. automatic milking system and with solid floors or rubber floors in the alleys. Hence, the study is not a totally random study. However, within these farms, study units were randomly selected. The selection of study farms was only within farms registered in NDHRS (Østerås et al., 2007), but more than 97 % of the dairy farms in Norway are registered in this database (Simensen et al., 2010).

This study was based on farmers participating voluntarily, hence one may speculate if some farms with e.g. low milk yield, bad udder health or dirty conditions due to poor design chose not to participate. In that case our findings might be skewed to the "better end" of the scale, however there are no indications that this was the case as there were mainly large variation in stall design parameters and cleanliness observations.

Cows of the Norwegian Red dairy breed are smaller than Holstein cows, partly explaining why smaller stall sizes are used in Norway. Shoulder height of the Norwegian Red dairy breed (NRF) is approximately 1.32 to 1.34 m (Nygaard, 1983; Sveberg et al., 2007; Ruud, unpublished data). Effects of farmer attitudes or management routines on different farms could influence on the results, but due to the large number of farms, this effect will probably be of minor importance. These effects are hence not fully included and discussed in present thesis.

Epidemiological field studies can only demonstrate associations, and caution should be taken to interpret cause-relationships. Field studies are however important in generating hypotheses, or to strengthen hypotheses previously set up from other studies. If it is possible to make a good and reasonable hypothesis, using controlled laboratory studies to follow up results from a field study will be a preferable solution. This means that both types of studies are very valuable, but at different stages in creating new knowledge.

Conclusion and practical application

The studies in present thesis provided data for good design of an optimal free stall regarding cleanliness in herds with cows of the same size as the Norwegian Red dairy breed (Table 3).

In this study, an optimal (clean) stall was equal to an open-fronted stall design (Figure 11). Such stalls were typically without any lower head rail or other restrictions between the top of a brisket locator (maximum height 0.1 m) and an upper head rail positioned 1 m above stall base. Positive effects of head rail position on stall cleanliness were found from a height of 0.7 m, and for cow cleanliness the effects were evident for all heights above 0.52 m.

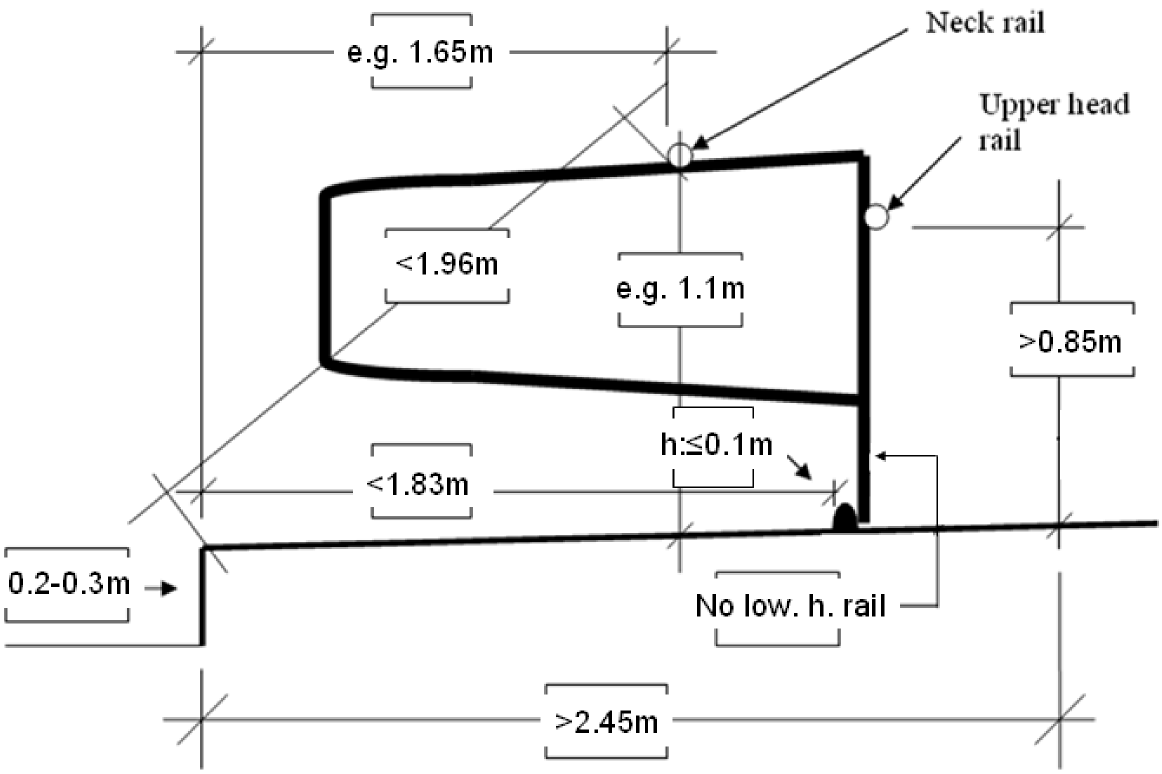

Figure 11. *In an optimal free stall according to the cleanliness and stall divider studies in present thesis, there should be no lower head rail, the upper head rail as well as the neck rail and brisket locator should be located as not to conflict with the dynamic space needed for raising, and there should be a soft stall base with sufficient bedding onto it. Brisket locator should be used, however the height and distance to rear curb should not exceed 0.10 and 1.83 m respectively.*

The optimal diagonal distance of a neck rail, was closer to the rear curb than 1.96 m.

Using a brisket locator with maximum height 0.10 m positioned closer to the rear curb than 1.84 m is recommended.

Associations between stall cleanliness and stall width and length was found, however were of less importance than expected. Optimal stall length was shorter than 2.45 m.

In a controlled study, flexible stall dividers were clearly preferred by the cows compared to fixed dividers. All stalls remained remarkably clean during this experiment.

Soft stall bases is mandatory in an optimal free stall as softer stall surfaces than 16 mm impact (typically multilayer mats and mattresses) is positively influencing on milk yield and was also associated with a lower risk for clinical mastitis, teat lesions and non-voluntary removal of cows. Such soft stall bases will also be positive regarding the herd income.

Use of bedding, even minor amounts, is positive for stall and cow cleanliness and should be used in an optimal stall.

Also cow density (number of cows per stall), cow tameness, indoor temperature and relative air humidity were found to be risk factors to cow cleanliness, however were not discussed in present thesis.

Finally, the study set up also illustrated that an epidemiological approach could be useful in a study on housing conditions.

Suggestions for further research

Several findings were found and discussed in present thesis, however, there is still need to investigate e.g. the following subjects:

Create further understanding of the point of time during the raising movements that defecation occurs in stalls with enclosed front versus open fronts using more direct observations of the defecation behaviour.

Investigating whether it is possible to use more narrow stalls with flexible stall partitions compared to fixed partition or open-fronted stalls compared to more enclosed stalls. Making an ASS-index (Accessible Stall Space Index) is of interest.

Further investigation on the materials used in the construction, e.g. steel, plastic, flat nylon straps, wood and fibre glass in different parts of the free stall. Yielding rails parts might be positive for the cow due to reduced contact pressure.

In present study an open fronted stall was cleaner than more enclosed stalls, and an alternative stall divider were not found to influence negatively on cleanliness. Does this mean that very simple stalls, e.g. with dividers attached as a plank on the floor could maintain cleanliness as good as traditional stalls? Is other traits than cleanliness influenced?

One could speculate that open stall constructions with less restrictions for the cow, may lead to an increased risk for that individuals could move to far forward and thus be trapped or hurt. Free stall design with a special focus on cow security using e.g. easy removable or flexible rails is of special interest.

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Lars Erik Ruud, Stange, June 2011.

Paper I

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Associations of soft flooring materials in free stalls with milk yield, clinical mastitis, teat lesions, and removal of dairy cows

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ABSTRACT

The objective was to test if there was an association between free-stall base softness and milk yield, incidence of clinical mastitis (CM), teat lesions, and removal of cows. In a questionnaire sent to 1,923 dairy farms presumed to be using free-stall housing, farmers were asked for information regarding housing and stall base; for example, the year of installation and the product name or brand of their mats or mattresses. This information was merged with data for milk yield, CM, teat lesions, and removal of cows extracted from the Norwegian Dairy Herd Recording System for the years after installation of mats or mattresses. After exclusion of invalid contributions, the data set consisted of 29,326 lactations for milk yield distributed over 363 free-stalled herds in Norway. The farms were stratified into 5 categories according to the softness of the stall surface measured as millimeter impact of a sphere with a diameter of 120 mm at 2-kN load: 1 = concrete, softness of 0 mm; 2 = rubber, softness of 1 to 8 mm; 3 = soft mats, softness of 9 to 16 mm; 4 = multilayer mats, softness of 17 to 24 mm; and 5 = mattresses, softness over 24 mm. Lactation curves were estimated as modified Wood's lactation curves using test-day data and mixed models with repeated measurements, adjusting for days in milk, parity, and softness of free-stall flooring. Herds on concrete free-stall bases yielded 6,727 ± 146 kg of milk from 5 to 305 days in milk. In comparison, herds showed a decrease of 0.3% on rubber, an increase of 2.4% on soft mats, an increase of 4.5% on multilayer mats, and an increase of 3.9% on mattresses. Compared with concrete, the hazard ratio (HR) of CM was less on rubber, multilayer mats, and mattresses [HR = 0.89 (0.79–0.99), 0.85 (0.73–0.996), and 0.80 (0.73–0.88), respectively]. Compared with concrete, the HR of teat lesions was less on rubber, soft mats, multilayer mats, and mattresses [HR = 0.41 (0.26–0.65), 0.33 (0.24–0.44), 0.12 (0.04–0.38), and 0.47 (0.33–0.67), respectively]. The HR of removal of cows was less on mattresses compared with concrete, rubber, soft mats, and multilayer mats, with HR = 0.90 (0.84–0.97), 0.88 (0.80–0.97), 0.86 (0.80–0.93), and 0.85 (0.76–0.95), respectively. A soft free-stall base contributed significantly to increased milk yield and fewer incidences of CM, teat lesions, and removal of cows.
Key words: free-stall base softness, milk yield, clinical mastitis, teat lesion

INTRODUCTION

Lying surfaces for dairy cows should provide thermal comfort and softness, be durable, and have sufficient friction to allow cows to stand up and lie down without slipping. They should help in keeping the cows clean and healthy and minimize daily labor requirements (Chaplin et al., 2000). Lying is an important and highly prioritized behavior in cattle, and normal lying time in free stalls is 8 to 16 h/d (Tucker and Weary, 2004). The duration could be influenced, among other factors, by housing and bedding (Krohn and Munksgaard, 1993). In a preference test setup, Wander (1974) found that dairy cows preferred the softness of 10 to 15 cm of sawdust in free stalls. Dairy cows have a strong preference for soft bedding materials, such as soft mattresses (Herlin, 1997; Rushen et al., 2001). Furthermore, lying time increases when softer flooring materials are introduced (Rushen et al., 2001). Interestingly, Major Bramley, the inventor of the free stall, introduced soft mats in the first free stalls in 1957 (Bramley, 1962). To provide a simple, physical method for measuring stall-base softness, Nilsson (1988) expressed softness as millimeter impact of a sphere (diameter = 100 mm at 2-kN load), a method later adapted to a sphere with the diameter of a cow's knee (diameter = 120 mm) by ADAS, United Kingdom (Dumelow, 1995) and applied by others; for example, Deutsche Landwirtschafts-Gesellschaft (DLG, 2009) in its testing procedures for mats and mattresses.

Milk yield is significantly decreased by clinical mastitis (**CM**), and all precautions that can reduce the incidence of CM are positive. It is important to maintain clean stall surfaces and environments that sustain the

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defense systems of the body (unbroken skin, immune system) to resist disease pathogenesis. Soft mats stay cleaner than concrete (Herlin, 1997), and clean stall surfaces are associated with a lesser rate of IMI (Schreiner and Ruegg, 2003). Furthermore, soft mats have a heat-insulating capacity (Nilsson, 1988), protecting the udder from being cooled. Ewbank (1968) demonstrated that cold flooring in stalls is associated with an increase in SCC. There was a reduction by almost 50% in the SCC in herds with rubber mats compared with concrete (Østerås and Lund, 1988), and Valde et al. (1997) found the incidence rate of mastitis reduced by 14% in herds with rubber mats compared with concrete floors. Teat lesions are painful for the animals, and the number of even minor injuries is associated with a greater SCC (Geishauser et al., 1999) and greater incidence of mastitis (Elbers et al., 1998). Apart from Østerås and Lund (1988) finding a greater incidence of teat lesions in tie stalls with concrete flooring compared with rubber mats, documentation on the effects of free-stall base softness on teat lesions is scarce.

Data on culling or removal of cows are used as an indicator of how the production environment influences the cows. The reasons for cows being removed from a herd are complex and range from disease to forming part of normal recruitment for the herd (Hadley et al., 2006). The most important reasons for removal in Holstein cows are reproductive disorders, udder disorders (including mastitis and teat injuries), and locomotor disorders (Beaudeau et al., 2000). Thomsen et al. (2007) described concrete-floored stalls as a risk factor for "loser cows;" that is, cows that often end up dying or being culled.

The main hypothesis was that soft free-stall bases would contribute to an increase in milk yield and a lowered incidence of mastitis and teat lesions. It was reasonable to make the hypothesis that a soft free-stall base, which is associated with a long lying time, would provide vulnerable cows a better opportunity for rest and recuperation, hence reducing the risk of removal. The objective was to test if there was an association between free-stall base softness and milk yield, incidence of CM, teat lesions, and removal of cows.

MATERIALS AND METHODS

Herds in the Study

Based on lists from a former survey (Sogstad et al., 2005), a questionnaire was sent to all known free-stall and loose-housed herds in Norway (n = 1,923) during the winter of 2004 to 2005. In the questionnaire, the farmers were asked about the type of flooring material in their free stalls, the brand of their mats or mattresses, if installed, and the year of installation, as well as some housing aspects. A total of 704 farmers responded to the questionnaire, giving a response rate of 36.6%. Of these, 601 had a free-stall system and were included in the study. Herds with unknown year of installation of mat or mattresses (n = 7), with more than one particular kind of free-stall base (n = 87), with a barn newer than the mats or mattresses (n = 4), with mats or mattresses older than 1998 if not concrete (n = 102), with a barn itself built before 1980 (n = 16), and with mats and mattresses installed in 2005 (n = 7) were excluded. Herds not registered in the Norwegian Dairy Herd Recording System (**NDHRS**) were also excluded (n = 15). The final data set consisted of 363 herds.

Free-Stall Base Softness

Deutsche Landwirtschafts-Gesellschaft (**DLG**) is a German organization that conducts thorough tests of commercial farming equipment, including mats and mattresses. With information about the brand name of free-stall base available in the questionnaire, the results from the DLG test reports (DLG, 2009) were used for categorization of softness (millimeter impact). Hence, softness was not measured on-farm. In the DLG test reports, softness was measured as millimeter impact of a sphere (diameter = 120 mm) at 2-kN load. Stall-base softness for each farm was categorized into one of the following 5 classes of softness: 1 = concrete, softness of 0 mm, hard free-stall base made of concrete without any cushion; 2 = rubber, softness of 1 to 8 mm, free stalls typically equipped with compact rubber mats; 3 = soft mats, mats with softness of 9 to 16 mm, for example, light "comfort mats" or rubber mats with rubber studs underneath them contributing to softness; 4 = multilayer mats, multilayer or other mats with softness of 17 to 24 mm; and 5 = mattresses, soft mattresses with softness over 24 mm. No other information about stall design or use of bedding was sought.

Cows in the Study

Data from each individual cow were extracted from the NDHRS database for the year after installation of mats or mattresses. The following data were collected: test day, kilograms of milk on test day, kilograms of concentrate fed on test day, information about disease on test day, parity, calving day, day of removal from the herd, and all disease treatments including day of treatment. The number of days from installation of new mats or mattresses and calving was calculated.

Lactations with calving before August 2001 and after July 2005 were excluded. All lactations starting with an abortion or with calving before, or in, the installation year were also excluded.

Milk Yield

Milk yields are weighed monthly on the farms and then reported to NDHRS. Test days with a daily milk yield <7 kg were deleted, as well as one recording >80 kg. Also, test days before DIM = 5 and test days after DIM = 330 were deleted. The milk-yield data set contained 226,686 test-day observations from 29,326 different lactations using 17,528 different cows and 363 different herds.

CM, Teat Lesions, and Cows Removed

In Norway, all medical treatments of animals must be done by a veterinarian, including mastitis treatments, and are then reported into the NDHRS database (Østerås et al., 2007). All recordings of CM, defined according to the International Dairy Federation (IDF, 1999), teat lesions, and cow removal were extracted from this database. A teat lesion was defined as acquired teat trauma or wound in conjunction with the skin, or an injury disturbing the milk stream, of a severity subject to veterinary treatments. All cows removed from the original herd in which they were registered in the NDHRS database, including cows sold to another herd or to slaughter, were considered as cows removed. The observation period for each lactation started 15 d before calving and ended either on the day of removal or 15 d before the next calving. The data set for the study of CM, teat lesions, and cows removed comprises 32,167 different lactations by 19,216 different cows within the 363 herds. Lactations with observation periods longer than 542 d (5% of the lactations) and one lactation with an obvious error in the removal date were excluded. After excluding these extremely long lactations, there were 31,779 lactations left, from 19,011 different cows and 363 different herds. These recordings were merged with a data set of unique lactations for each cow, and all observations of CM between start and end of the observation period were included. Only the first observation of CM was included in a survival analysis. This data set was merged with the information about stall-base softness from each farm. The same procedure was used for the teat lesions. Finally, a new data set was made (n = 7,923) with all primary cases of CM, merged with all the secondary cases of CM. Secondary cases of CM were sought at 100 d after the primary case of CM. The first 4 d after a primary case were counted as retreatment of the primary case of CM and, thus, such cases were excluded as a secondary case. The removal day and reason registered in the NDHRS database were merged with the lactation information. The observation period used in the survival analysis for removal was from calving to removal, censored for 200 DIM or, in cases of early calving, at 15 d before next calving. Cows listed as dead or condemned were cows registered as dead or condemned in the NDHRS database as cause for removal.

Statistical Analysis

Milk Yield. To estimate the lactation curve, a modified model according to Wilmink (1987) was fitted, adapted according to the lactation curve presented by Wood (1967). These milk-yield data were fitted into a mixed model using the PROC MIXED procedure in SAS (SAS version 9.1. from SAS Institute Inc., Cary, NC) with test-day milk yield as the dependent variable. The traits DIM, lnDIM, whether the cow was diseased on the test day, free-stall base softness class, test-day year, and test-day month were used as fixed variables. The final model included interaction between DIM, lnDIM, and softness class. The mixed models were analyzed with repeated measurements applying autoregressive correlation type 1 matrix AR(1) and were fitted separately for parity 1, 2, 3, and >3. There was no backward or forward exclusion in the model construction. The model estimates were fed into a spreadsheet to construct the milk curve per softness class and to estimate the model-based 5 to 305 DIM total mean milk yields as the sum of estimated test-day milk yield. Milk yield was calculated separately per parity. Finally, to check the overall fit of the model-based results, the mean and standard deviation for each lactation month (each 30-d interval) were estimated from the raw data within each softness class.

The general model used for estimating Y was

$$\begin{aligned} Y_{my} = \beta_0 + \beta_1 \times \mathrm{DIM} + \beta_2 \times \mathrm{lnDIM} + \beta_3 \times \mathrm{DIM} \\ \times \mathrm{soft}_x + \beta_4 \times \mathrm{lnDIM} \times \mathrm{soft}_x + \mathrm{soft}_x + \beta_5 \\ \times \text{test-year}_x + \beta_6 \times \text{test-month}_x + Z_l + e, \end{aligned}$$

where Y_{my} = test-day milk yield, β_0 = intercept, β_i = estimated coefficient, soft_x = association of softness of bedding material, Z_l = random effect of lactation, and e = random error.

Confidence interval for 305-DIM milk yield based on model estimates was established by applying estimates with standard error using simulation with @RISK, version 5.5.0, (Palisade Corporation, Ithaca, NY).

Table 1. Description of study herds (n = 363 herds) stratified according to free-stall softness (±SD)

	Softness class[1]				
Variable	Concrete	Rubber	Soft mats	Multilayer mats	Mattresses
Herds, n	112	44	129	19	59
Cows, n	5,882	1,725	5,875	1,023	3,023
Parities, n	10,837	2,683	9,640	1,443	4,723
Mean parity number	2.39 (1.54)	2.37 (1.45)	2.34 (1.49)	2.26 (1.34)	2.35 (1.43)
Test days, n	83,532	20,367	74,759	11,005	37,023
Test-day milk yield, kg	22.1 (7.0)	22.5 (7.0)	22.9 (7.1)	23.8 (7.7)	23.4 (7.7)
Test-day DIM	139 (84)	139 (83)	140 (85)	138 (84)	140 (85)
Proportion of test days with disease	0.003	0.003	0.003	0.003	0.002
Test-day year	2,003.5 (1.2)	2,004.0 (1.1)	2,003.9 (1.1)	2,004.4 (0.8)	2,004.1 (1.1)
Test-day month	6.5 (3.5)	6.5 (3.5)	6.5 (3.5)	6.7 (3.4)	6.5 (3.5)
Year of building	1,990.3 (5.2)	1,995.1 (7.1)	1,994.6 (6.7)	2,000.1 (4.1)	1,999.1 (6.1)
Year of mat	1,990.4 (5.3)	2,002.0 (1.7)	2,001.5 (1.4)	2,002.8 (0.9)	2,002.2 (1.3)
Concentrate, %[2]	36.3 (6.5)	35.9 (7.6)	36.6 (6.6)	34.6 (8.2)	36.7 (7.8)
Concentrate, kg/cow per d	6.5 (2.8)	6.7 (2.8)	6.7 (2.8)	6.7 (2.8)	6.6 (3.2)

[1]Softness measured as millimeter impact of a sphere (diameter = 120 mm) at 2-kN load. Concrete = 0 mm impact; rubber = 1 to 8 mm impact; soft mats = 9 to 16 mm impact; multilayer mats = 17 to 24 mm impact; mattresses = impact >24 mm.

[2]Concentrate as percentage of total energy intake on herd level.

Mastitis, Teat Lesions, and Removal. The health data were analyzed using the survival analysis PROC LIFETEST and PROC PHREG in SAS (SAS version 9.1. from SAS Institute Inc.). The hazard ratio (**HR**) for a cow to develop CM or a teat lesion or for removal was estimated using Cox regression analyses (Cox, 1972) with the general hazard function [h for ith individual in kth herd (stratum)]:

$$h_{ik}(t) = \lambda_{i0}(t)\ \exp(\beta_{ik}),$$

where β in this particular study was defined with the fixed covariates parity (1, 2, 3, and >3), softness class, and calving year; t was time from start of observation to event (CM, teat lesion, or removal); and λ was the baseline hazard. All variance estimate survival models were analyzed with robust sandwich methods using ties = exact and herd as the id variable (Lin and Wei, 1989).

Data observations were censored at end of lactation, at next calving, or at 305 DIM if there was no calving or removal. Concrete, rubber, soft mats, multilayer mats, and mattresses were included as covariates and adjusted for parity 1, 2, 3, and >3 and recording year as fixed effects. The survival analyses were analyzed for the period from 15 d before calving until primary case of disease or removal occurred. The period from the primary case of CM to a secondary case of CM was analyzed in a separate model. Separate models were made for CM, teat lesions, and removal. If significant, the estimates were adjusted for year of calving. The significance level was $P \leq 0.05$.

RESULTS

Herd Characteristics and Free-Stall Flooring

The average herd size during 2005 for the herds was 26.5 ± 14.7 (mean ± SD) standardized cow-years within a range of 6.4 to 92.2 (cow-year = sum of number of days within a herd from first calving to culling within 1 yr, divided by 365, corresponding to mean number of cows in the herd at any time). Norwegian Red dairy breed was used as the main breed (98.8% of the cows). The feed ration used on the farms, calculated on an energy basis, consisted of 37.1% concentrate, 45.3% grass silage, 12.6% pasture, and 5.0% other feedstuff. The most common free-stall bases were concrete and soft mats (Table 1).

Milk Yield

Multilayer mats and mattresses were associated with greater milk yield compared with concrete floorings and rubber mats. Soft mats were associated with a milk yield greater than that with concrete and rubber mats but less than that with multilayer mats and mattresses. Multilayer mats and mattresses were associated with a milk yield 1.1 to 5.8% greater than that for concrete stall bases. The mean and standard deviation of test-day milk yield, DIM, test-day year, and test-day month are presented in Table 1. In Table 2, the raw mean test-day milk-yield data, distributed in 30-d intervals, are presented. Table 3 presents the estimated parameters for the model-based milk curve within parities, and Table

Table 2. Mean test-day milk yield (kg/d) from the raw data in free-stalled dairy herds (n = 363 herds) within each free-stall base softness class distributed in 30-d intervals (±SD)

Lactation period (DIM)	Softness class[1]									
	Concrete		Rubber		Soft mats		Multilayer mats		Mattresses	
	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
5–30	8,694	25.43 (6.77)	2,064	25.72 (6.24)	7,667	25.83 (6.56)	1,122	26.42 (6.88)	3,821	26.00 (7.00)
31–60	10,022	27.11 (6.81)	2,503	27.69 (6.54)	8,896	28.14 (6.75)	1,316	29.15 (7.41)	4,419	28.85 (7.43)
61–90	9,578	26.03 (6.48)	2,352	26.53 (6.36)	8,614	27.01 (6.48)	1,266	28.10 (7.27)	4,210	27.94 (7.09)
91–120	9,235	24.41 (6.09)	2,238	24.84 (5.87)	8,248	25.43 (6.14)	1,261	26.39 (6.74)	4,108	26.17 (6.59)
121–150	8,913	22.79 (5.63)	2,200	23.12 (5.76)	7,944	23.79 (5.79)	1,196	24.58 (6.57)	3,961	24.32 (6.26)
151–180	8,524	21.17 (5.32)	2,154	21.31 (5.51)	7,674	21.95 (5.47)	1,159	22.91 (6.34)	3,724	22.63 (6.09)
181–210	8,170	19.60 (5.15)	2,002	19.77 (5.41)	7,261	20.28 (5.22)	1,062	21.27 (5.89)	3,644	20.73 (5.85)
211–240	7,599	17.91 (4.89)	1,858	18.10 (5.20)	6,782	18.56 (5.00)	971	19.58 (5.63)	3,323	18.81 (5.74)
241–270	6,424	16.06 (4.63)	1,556	16.40 (4.92)	5,888	16.76 (4.74)	835	17.45 (5.22)	2,845	16.95 (5.41)
271–300	4,105	14.67 (4.36)	940	15.10 (4.89)	3,815	15.27 (4.57)	515	15.66 (5.14)	1,911	15.76 (5.14)
301–330	1,924	14.17 (4.28)	410	14.48 (4.58)	1,662	14.75 (4.53)	249	15.04 (5.15)	938	14.84 (4.85)

[1]Softness measured as millimeter impact of a sphere (diameter = 120 mm) at 2-kN load. Concrete = 0 mm impact; rubber = 1 to 8 mm impact; soft mats = 9 to 16 mm impact; multilayer mats = 17 to 24 mm impact; mattresses = impact >24 mm.

4 present the estimated 5 to 305 DIM milk yield in kilograms, based on these model estimates distributed on parity and softness class. All parameter estimates for all parities in Table 3 concerning softness class were significant ($P < 0.001$). In the total population, 36.5% of the animals were in parity 1, 26.6% were in parity 2, 17.3% were in parity 3, and 19.6% were above parity 3. No difference in distribution of animals regarding parity was found between softness classes.

CM

There were 4,309 (13.6%) lactations with at least one case of CM before 305 DIM (Table 5). Adjusted for

Table 3. The model-based estimates (SE) according to mixed models estimating the test-day milk yield (kg/d) for dairy cows in free stalls (n = 363 herds) distributed by parity[1]

Variable	Class	Parity 1	2	3	>3
Intercept		10.195 (0.348)	14.390 (0.468)	13.771 (0.618)	14.560 (0.561)
Ill on test day	No	4.049 (0.189)	5.244 (0.237)	5.407 (0.300)	5.219 (0.237)
	Yes	0	0	0	0
DIM		−0.067 (0.0009)	−0.103 (0.001)	−0.120 (0.002)	−0.120 (0.002)
lnDIM		3.517 (0.077)	4.239 (0.107)	5.161 (0.146)	4.944 (0.141)
Softness class[2]	Concrete	2.012 (0.320)	2.908 (0.447)	4.734 (0.596)	1.345 (0.572)
	Rubber	1.669 (0.459)	1.880 (0.608)	5.325 (0.815)	1.007 (0.823)
	Soft mats	1.057 (0.325)	1.731 (0.451)	2.578 (0.608)	0.498 (0.591)
	Multilayer mats	1.361 (0.556)	0.312 (0.767)	1.094 (0.998)	−2.125 (1.064)
	Mattresses	0	0	0	0
DIM × softness class	Concrete	0.005 (0.001)	0.017 (0.002)	0.021 (0.002)	0.013 (0.002)
	Rubber	0.003 (0.002)	0.014 (0.002)	0.021 (0.003)	0.009 (0.003)
	Soft mats	0.003 (0.001)	0.011 (0.002)	0.013 (0.002)	0.004 (0.002)
	Multilayer mats	−0.0002 (0.002)	0.0005 (0.003)	0.006 (0.004)	0.006 (0.004)
	Mattresses	0	0	0	0
lnDIM × softness class	Concrete	−0.723 (0.092)	−1.376 (0.130)	−1.883 (0.175)	−0.936 (0.169)
	Rubber	−0.573 (0.133)	−1.107 (0.177)	−2.057 (0.240)	−0.734 (0.244)
	Soft mats	−0.382 (0.094)	−0.803 (0.131)	−1.042 (0.179)	−0.332 (0.174)
	Multilayer mats	−0.164 (0.161)	−0.004 (0.223)	−0.451 (0.293)	0.072 (0.314)
	Mattresses	0	0	0	0
Random lactation, %		3.5	2.5	2.2	2.0
Random error, %		96.5	97.5	97.8	98.0

[1]Adjusted for DIM; lnDIM; cows ill on test day; softness class of free-stall base; interaction between DIM, lnDIM, and softness; and test-day year and test-day month. Estimates are adjusted to test-day year 2006 and month of December. Estimates for test-day year and test-day month are not shown. One model per parity 1, 2, 3, and >3.

[2]Softness measured as millimeter impact of a sphere (diameter = 120 mm) at 2-kN load. Concrete = 0 mm impact; rubber = 1 to 8 mm impact; soft mats = 9 to 16 mm impact; multilayer mats = 17 to 24 mm impact; mattresses = impact >24 mm.

Table 4. Estimated 5 to 305 d milk yield in kilograms based on the model estimates given in Table 3 stratified on free-stall softness class and parity (n = 363 herds)[1]

	Softness class[2]				
Item	Concrete	Rubber	Soft mats	Multilayer mats	Mattresses
Parity					
1	6,063 [6,056, 6,070][a]	6,077 (+0.2) [6,061, 6,093][a]	6,169 (+1.7) [6,162, 6,176][b]	6,412 (+5.8) [6,386, 6,438][d]	6,248 (+3.0) [6,242, 6,254][c]
2	6,934 [6,923, 6,944][b]	6,840 (−1.4) [6,814, 6,866][a]	7,113 (+2.6) [7,107, 7,129][c]	7,336 (+5.8) [7,298, 7,376][e]	7,224 (+4.2) [7,214, 7,235][d]
3	7,312 [7,296, 7,331][a]	7,271 (−0.6) [7,229, 7,313][a]	7,499 (+2.6) [7,480, 7,518][b]	7,611 (+4.1) [7,546, 7,676][c]	7,631 (+4.4) [7,616, 7,648][c]
>3	7,167 [7,153, 7,187][a]	7,187 (+0.3) [7,147, 7,225][a]	7,373 (+2.9) [7,356, 7,390][b]	7,247 (+1.1) [7,184, 7,310][a]	7,500 (+4.6) [7,484, 7,512][c]
Overall estimate[3]	6,727 [6,724, 6,730][b]	6,704 (−0.3) [6,696, 6,709][a]	6,886 (+2.4) [6,884, 6,890][c]	7,029 (+4.5) [7,019, 7,040][e]	6,992 (+3.9) [6,989, 6,995][d]

[a–e]Within a row, different superscript letters of significance indicate different milk yield according to confidence intervals.

[1]Numbers in parentheses indicate percent increase in milk yield versus concrete, and numbers in brackets are 95% CI. Confidence intervals are based on SEM simulated in @RISK (version 5.5.0, Palisade Corporation, Ithaca, NY).

[2]Softness measured as millimeter impact of a sphere (diameter = 120 mm) at 2-kN load. Concrete = 0 mm impact; rubber = 1 to 8 mm impact; soft mats = 9 to 16 mm impact; multilayer mats = 17 to 24 mm impact; mattresses = impact >24 mm.

[3]The overall estimated milk yield is the mean weighted according to distribution of parity 1, 2, 3, and >3, with weightings 0.365, 0.266, 0.173, and 0.196, respectively.

parity and calving year, there was less CM on rubber [$P < 0.05$; HR = 0.89 (0.79–0.99)], multilayer mats [$P < 0.05$; HR = 0.85 (0.73–0.996)], and mattresses [$P < 0.001$; HR = 0.80 (0.73–0.88)] compared with concrete floors. The risk of CM was greater with soft mats [$P < 0.05$; HR = 1.09 (1.02–1.17)] compared with concrete and less with multilayer mats [$P < 0.01$; HR = 0.78 (0.67–0.91)] and mattresses [$P < 0.001$; HR = 0.73 (0.67–0.81)] versus soft mats. The risk of relapsing into CM within the same lactation was less on mattresses ($P < 0.05$) versus concrete floors, with HR = 0.76 (0.60–0.97). No other differences regarding new cases of CM between softness classes were found.

Teat Lesions

There were 323 (1.0%) lactations with teat lesions before 305 DIM (Table 5). Adjusted for parity and calving year, the risk of teat lesions was less with rubber, soft mats, multilayer mats, and mattresses than with concrete free-stall bases (all with $P < 0.001$), with HR = 0.41 (0.26–0.65), HR = 0.33 (0.24–0.44), HR = 0.12 (0.04–0.38), and HR = 0.47 (0.33–0.67), respectively. Multilayer mats had a lesser HR [0.28 (0.09–0.93)] than did rubber ($P < 0.05$). No other differences in teat lesions between softness classes were found.

Removal

There were 7,656 (24.1%) lactations ending with removal within 200 DIM (Table 5). The risk of removal was less with mattresses compared with concrete ($P < 0.01$), rubber ($P < 0.01$), soft mats ($P < 0.001$), and multilayer mats ($P < 0.01$), with HR = 0.90 (0.84–0.97), HR = 0.88 (0.80–0.97), HR = 0.86 (0.80–0.93), and HR = 0.85 (0.76–0.95), respectively. No other differences in removal between softness classes were found. Altogether, 296 (0.9%) lactations ended in death or condemned meat at slaughter (Table 5). There was no difference in death or condemned meat between softness classes in raw data or in the total population. All softness classes except multilayer mats were close to significantly ($P < 0.10$) better than concrete. When analyzing only removed animals, concrete was a greater risk factor for death and condemned meat compared with all the other softness classes ($P < 0.05$), with HR = 1.30 (1.02–1.67).

DISCUSSION

Softer floorings were, in general, associated with increased milk yield. In addition, softer floorings were

Table 5. Health events (raw data) distributed on free-stall softness class (n = 363 free-stalled dairy herds)

Softness class[1]	Lactations, n	With clinical mastitis, n (%)[2]	With teat lesions, n (%)[2]	Removals, n (%)[2]	Dead or condemned, n (%)[2]
Concrete	11,863	1,671 (14.1)	203 (1.7)	2,862 (24.1)	127 (1.1)
Rubber	3,021	371 (12.3)	20 (0.7)	741 (24.5)	21 (0.7)
Soft mats	10,292	1,522 (14.8)	57 (0.6)	2,556 (24.8)	93 (0.9)
Multilayer mats	1,564	178 (11.4)	4 (0.3)	390 (24.9)	14 (0.9)
Mattresses	5,039	567 (11.3)	39 (0.8)	1,107 (22.0)	41 (0.8)
Total	31,779	4,309 (13.6)	323 (1.0)	7,656 (24.1)	296 (0.9)

[1]Softness measured as millimeter impact of a sphere (diameter = 120 mm) at 2-kN load. Concrete = 0 mm impact; rubber = 1 to 8 mm impact; soft mats = 9 to 16 mm impact; multilayer mats = 17 to 24 mm impact; mattresses = impact >24 mm.

[2]Percent of lactations.

generally associated with decreased incidence of CM, teat lesions, and removal.

Milk Yield

Earlier studies investigating the associations of stall flooring softness on milk yield used small populations and did not reveal significant associations (Chaplin et al., 2000; Rushen et al., 2001). Hence, this study was based on a questionnaire aimed at a large study population. In this study, test-day milk yield was used as demonstrated by Wilmink (1987) and estimated the shape of the lactation curves stratified by parity. The relative risk for CM, teat lesions, and removal normally increases with parity, and hence, herd composition could influence raw data studies. However, this was corrected for, as models with repeated measurements will make the estimates as unbiased as possible owing to, for example, different parities and removal strategy. In an epidemiological study like this, diseases that are more frequent in one softness class, e.g., CM, teat lesions, or lameness, could influence milk yield, but such correlated associations have not been investigated. The milk yield estimated in Table 4 corresponds well with the milk yield raw data for all study herds in Tables 1 and 2 and with mean milk yield from the total population in the NDHRS database with 6,921 kg per cow year in 2008 (Tine rådgivning, 2009). According to our hypothesis, the greatest milk yield was expected on mattresses, but the milk yield found in this group was not consistently greater than that for multilayer mats (Table 4). As well as the softness itself, one could speculate that incidence of disease, group size, management routines, or the mattress group was less homogenous than other product groups and could play a role. According to the test reports from DLG (DLG, 2009), for example, soft mattresses have a greater tendency to be persistently compressed than harder stall surfaces, resulting in properties changing toward less softness.

CM

The risk of CM was less for rubber, multilayer mats, and mattresses versus concrete floors. This supports the findings of Valde et al. (1997), who found less CM in cows in free-stall housing with rubber mats compared with cows in concrete-floored stalls. In this study, we had no information about causal agents related to CM, and the association was estimated on generic mastitis reported to the NDHRS database. Less hygienic housing conditions are a risk factor for CM (Elbers et al., 1998); soft surfaces stay cleaner (Herlin, 1997) and clean stalls are associated with a lower bacterial count on teat ends (Zdanowicz et al., 2004). However, the link to udder health is more unclear. Furthermore, the heat-insulating capacity of a product increases with softness of mats (Nilsson, 1988) and could play a role in preventing mastitis because "cold udders" have greater SCC (Ewbank, 1968). The insulation and other physical properties of the stall surface in relation to indoor temperature could influence lying behavior (Manninen et al., 2002). On soft mats, the risk of CM was greater than on concrete floors, but no such association could be seen with teat lesions. This suggests that there is sufficient traction on soft mats to avoid teat lesions. Practical experience has shown that permanent pits develop over time, especially on foam mats, under the pressure of cow claws, making the mat surfaces dirtier and influencing the incidence of CM. New cases of CM were more frequent on concrete floors than on the other surfaces in the present study, but no studies on new cases of CM with respect to free-stall base softness were found in the literature.

Teat Lesions

As a cow rises, it needs good traction against the floor. If the cow slips during rising, it will immediately try to get its feet under its body again, which often results in the cow tramping on its own teats (Krohn and Munksgaard, 1993). The low incidence of teat lesions found in all softness classes compared with concrete floors could be an association of improved traction rather than of softness itself, as indicated by Nilsson (1988). Lesser incidence rates of teat lesions on rubber mats compared with concrete floors were found by Østerås and Lund (1988). Interestingly, the incidence rate of teat lesions reported to NDHRS decreased from 2.7% in 2003 to 1.3% in 2008 (NCHS, 2009). This reduction might be a consequence of new regulations making multilayer mats or mattresses mandatory for all cows in Norway since 2006. The prevalence of concrete floors has been drastically reduced, and multilayer mats and mattresses have increased by the same order of magnitude (L. E. Ruud et al., unpublished data).

Removal

Associations of lesser risk of removal were identified for all soft free-stall bases compared with concrete floors. The reasons for cow removal from a herd are complex, ranging from diseases to being a part of normal recruitment to the herd (Hadley et al., 2006). Whether the lesser risk of removal on mattresses versus concrete floors found in this study was an effect of stall-base softness on cow longevity or differences in the farmers' attitudes or management requires more research.

General Discussion

Finding associations of stall-base softness with milk yield and health incidences was not a straightforward exercise because the associations investigated could be biased by feeding, season, breed, and herd composition, as well as other housing and management effects. One more ideal comparison would be to use the herd as its own control, comparing results before and after installation of mats and mattresses. Yet, change in stall surface often was associated with new buildings, change in ownership, season, and herd composition. Hence, a comparison within a farm could introduce even more bias. Age of building was different between softness classes, with concrete being older than rubber and soft mats, and barns with multilayer mats and mattresses being newer. Regarding the age of the stall surface itself, only concrete was older than the other softness classes. Year is, therefore, corrected for in the models. Amount and frequency of adding new bedding could in itself affect the stall-base softness (Wander, 1974). Even if there were no information about use of bedding, a field study in Norwegian free-stalled dairy herds (L. E. Ruud et al., unpublished data) revealed that only minor amounts of bedding were used (0.6 L per free stall). It is reasonable to conclude that the actual use of bedding did not influence the results of this study. Sand or straw-bedded stalls are very uncommon in Norway because of the limited availability of such bedding materials.

CONCLUSIONS

A softer free-stall base was associated with greater milk yield and lesser incidence of CM, teat lesions, and removal compared with harder stall surfaces. Concrete floors, especially, but also hard rubber mats, should be avoided as stall bases in free stalls because they were associated with lesser milk yield and greater incidence of CM, teat lesions, and removal. Soft floorings should clearly be selected in free stalls for dairy cows, especially when greater milk yield or a reduction in the incidence of CM, teat lesions, or removal of cows is the objective.

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Paper II

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Free-stall cleanliness is affected by stall design

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ABSTRACT

The objective of this study was to describe free-stall design and free-stall contamination in a cross sectional field study and to evaluate the effect of free-stall design on free-stall cleanliness. Five trained observers recorded cleanliness and use of bedding in 7 different sectors in 15 random selected free-stalls in each of 232 dairy herds. Of these, 8 herds were excluded from the statistical analyses due to stalls recently being cleaned out despite instructions not to do so. The observers also recorded the position of head and neck rails as well as stall width and construction of a possible brisket locator. The free-stall base was divided into seven sectors and the cleanliness of each sector was scored using a five grade scale reflecting the degree of contamination of each section. Two types of contamination were registered; faeces fallen on stall base (FAECES) and wet footprints (FOOT). Mean stall base length was 2.39 ($\pm$0.21) m when placed against wall and 2.23 ($\pm$0.11) m in a double row. Mean height of the neck rail was 1.07 ($\pm$0.05) m, upper head rail 0.90 ($\pm$0.15) m and lower head rail 0.37 ($\pm$0.18) m. Contamination was mainly observed in the three rear sectors of the stalls. The most important factors in improving stall cleanliness on the basis of FAECES, in ranked order, were found to be: amount of bedding >1.0 L, diagonal stall length$\leq$1.96 m, absence of lower head rail, stall length<2.30 m, brisket locator distance$\leq$1.83 m, stall width>1.13 m and upper head rail >0.70 m. Regarding FOOT contamination, the most important preventive factors were, in ranked order: amount of bedding >0.5 L, soft stall base with >0.5 L of bedding, brisket locator height$\leq$0.10 m, upper head rail >1.0 m, concrete stall base and stall width$\leq$1.13 m.

1. Introduction

Major Bramley invented the free-stall in his attempts to reduce the usage of bedding material as he realized that the animals had to be restricted in some way in order not to foul their bedding or get dirty when lying down (Bramley, 1962). The free-stall design must allow the cows to unhindered lie down, lie and rise easily and at the same time the construction should also contribute in keeping the cows and stall clean. Studies by Schmisseur et al. (1966) confirmed that free-stall housing kept cows cleaner and reduced bedding requirements by 75% compared to loose housing. Later, several studies have investigated different aspects of free-stall design (e.g. Bickert, 2000; Weary and Taszkun, 2000), but the connection between free-stall design and stall cleanliness still seems to be poorly documented. However, e.g. installing a neck rail in a free-stall, actually reducing the accessible length of the stall, improves the cleanliness of the free-stall, while wide stalls tends to be more soiled (Tucker et al., 2005). Further Gygax et al. (2005) discovered that enlargement of free-stalls increased the degree of soiling of the rear end of the stall and increased the number of dung droppings in the same area, whereas increased stall occupancy was found to be associated with a more contaminated free-stall base (Gaworski et al., 2003). No information on the connection between free stall floor length and free stall cleanliness was found, however Gjestang (1980) showed that

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for cows in tie stalls, cow cleanliness was improved when the length of the stall floor was reduced. Free-stalls equipped with mats stays cleaner than concrete floored stalls (Herlin, 1997), and use of bedding material is an important factor in keeping the cows clean (e.g. Nygaard, 1979), but the link to free-stall cleanliness is less clear.

The origin of faeces in free-stalls is, either from cows standing or lying in the stalls defecating directly on the stall base, or is following the cows from the alley into the stalls. Stall contamination could also be as splashing from cow activities in the alley. Stall design influences on the space accessible for the cows in the stalls and thereby the cows movements and positions, hence e.g. a short stall or a restrictive neck rail position, influences on the possibility for the cow to contaminate the stall base as illustrated by e.g. Gygax et al. (2005) and Tucker et al. (2005). The main hypothesis of this study was therefore that a stall design with less space accessible for the cow will contribute to a cleaner stall. The aim of this study was to describe the level of contamination in free-stalls, and to investigate the effect of free-stall design on stall cleanliness.

2. Materials and methods

2.1. The herds

This study was part of a larger descriptive and cross-sectional project on identifying optimal parameters in free-stall housing, where the selection of study farms reflects the entire project. From a questionnaire sent to all dairy advisers in Norway, a list was obtained of 2400 herds that were presumed to be housed in free-stalls. The farmers received a questionnaire covering several aspects of their free-stall housing system. To be included in the study, the farmers had to fulfil our inclusion criteria; volunteering to participate, herd size > 20 standardized cow-years based on the year 2005 (cow-year = sum of number of days within a herd from calving to culling within one year, divided by 365), and barns built from 1995 to 2005. As we expect some housing systems to be common in the future, all farms with robotic milking ($n = 44$), with solid concrete floors ($n = 80$) or solid rubber floors ($n = 16$) in the alleys were included in the study. As most farms had slatted floors, herds on slatted floors fulfilling the inclusion criteria were included only if they were located in the same municipality as farms mentioned above. The material used in this study consisted of 232 free-stalled dairy herds located all over Norway. As we wanted to study certain effects of alley flooring in other parts of the project, herds on solid concrete floors or rubber in the alleys are overrepresented in our dataset compared to the total population. This study is therefore not a random study, but a stratified cross-sectional descriptive study with random selection within groups, e.g. cows, stalls, cleanliness observations etc. From the initial phase of the free-stall project, the distribution of floor types in the alleyways in free-stall housed herds in Norway was approximately 80% slatted concrete floors, 18% solid concrete floors and 2% solid rubber floors. Floors in the selected 232 farms comprised 57.3% slatted concrete floors, 34.5% solid concrete floors and 6.9% solid rubber floors.

2.2. Observations

During the indoor feeding period from September 2006 until May 2007, 232 herds were visited once by one of five trained observers. To standardize the data collection, an initial two-day training session followed by three additional training sessions during the recording period was performed. Two of the observers conducted the majority of the registrations (73%) and had regular meetings between farm visits to enhance the consistency in data recording. A systematic protocol was used to record data on each farm. Additionally data was analyzed for significant clustering effect of observer to ensure no significant differences in recording during the study. On each farm the object was to choose 15 stalls for cleanliness and bedding observations by selecting every second, third etc. stall, dependent on the herd size (n stalls/15 and then closest integer). Each stall base was divided into seven sectors (Fig. 1). Some farmers had not followed the required routines regarding stall cleanliness (they were instructed not to clean out excreta or add bedding that actual day before until after our registrations in the stalls), consequently the stall contamination part of this study includes only 224 herds. In total, stall cleanliness was observed in 3,459 stalls on 224 farms with stall sector as unit in the statistical models.

2.3. Free-stall design

In each farm, the mid-stall in the row against a wall and the mid-stall located in a double row were selected and parameters recorded as illustrated in Fig. 2. For each type of stall, at least 4 other stalls per row of stalls were also measured to secure that the middle stall was representative for that specific type of stall in that herd. Each dirtiness recording was then linked to the correct stall type measure

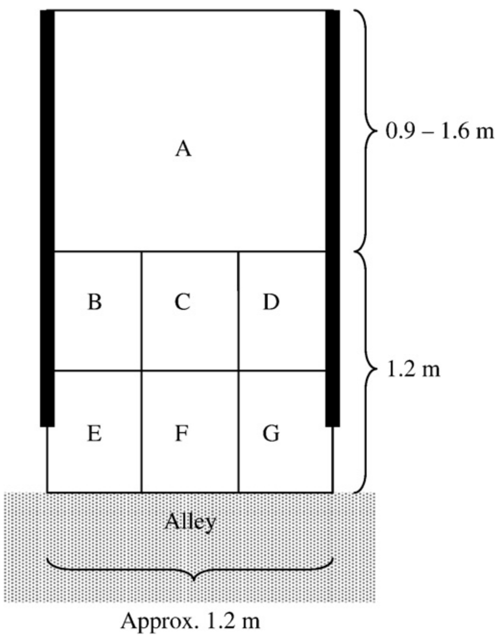

Fig. 1. The free-stall base was divided into 7 sectors (A to G) where cleanliness was scored individually on a scale of 1 to 5.

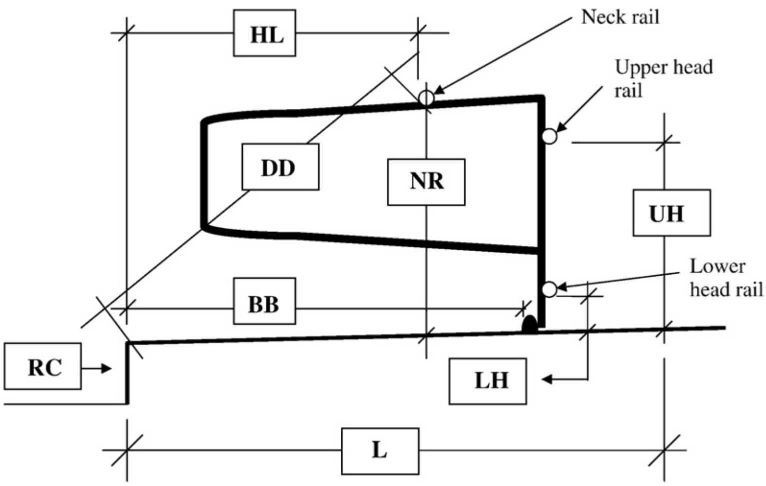

Fig. 2. Free-stall design parameters. L is free-stall length, NR is neck rail height, DD is diagonal distance, HL is horizontal neck rail distance, UH is upper head rail height, LH is the lower head rail distance and RC is the height of rear curb. BB is the position of brisket locator.

within that herd. It was controlled that all selected free-stalls were undamaged. As herd size is small in Norway, only two study farms had more than one pen of lactating cows. Free-stall length was defined as the distance from the rear curb to the wall or to the centre of a double row, and stall width as the horizontal distance between the dividers (inside measurement). In addition, position of neck rail was recorded as the height above stall base and the diagonal distance was the shortest distance from the rear curb to the neck rail. Horizontal neck rail distance was calculated and was the horizontal distance from rear curb to neck rail, however, there was a significant correlation between horizontal neck rail distance and neck rail height in our data. In consequence the diagonal neck rail distance was used to describe the neck rail position in the cleanliness models. Rear curb height was the distance from floor in the alley to the top of the stall base including mats or mattresses. Brisket locator height was the distance from stall base (on the cow side) to the top of the brisket locator, and the brisket locator length was the distance from the rear curb to the nearest side of the brisket locator.

2.4. Free-stall base

Free-stall base was classified into three groups according to softness, measured as millimeters of impact of a sphere ($d = 120$ mm) at 2 kN load, a method used by, e.g., Deutsche Landwirtschafts-Gesellschaft (DLG, 2009). Softness was not measured on-farm in the present study, but the DLG test reports for the different commercial mats and mattresses were used as a guideline for allocating the free-stall bases into the categories.

Stall base softness categories were grouped as follows:

1. Hard base with no or limited cushion — Typical softness was 0 mm. Hard base made of concrete and usually with sawdust as bedding.
2. Rubber mats — Typical softness was four to 15 mm. Stalls usually equipped with compact rubber mats with thickness normally between 15 and 30 mm.
3. Soft mats and mattresses — Typical softness was 16 to 40 mm. Soft mats (usually 30 to 40 mm thick), and mattresses (usually 40 to 100 mm thick).
4. Mixed free-stall base — Stall bases within more than one category, e.g. rubber mats and concrete floors.

2.5. Bedding

The type of bedding was registered and classified into one of the following categories:

1. Sawdust — Sawdust or wood shavings.
2. Straw — Chopped or uncut straw.
3. Peat — Dried peat.
4. Sand — All types of sand bedded stalls.
5. No use — No bedding used.

The amount (volume) of bedding in sectors B to G (see Fig. 1) was recorded by gently removing the bedding material into a five litre bucket with a litre scale. The volume of bedding in sector A was not recorded, owing to the sector varying in size and design, e.g. with or without brisket locator, and also because most of this sector is not accessible to the cows for lying on.

2.6. Scoring stall cleanliness

Stall cleanliness was scored approximately 2 h after morning feeding in each of 7 sectors in the same 15 stalls mentioned above. After visual inspection, we recorded how the faeces had been deposited in the stall:

1. Faeces fallen in the stall (FAECES) — Faeces deposited from a cow directly on to the stall base. This type of contamination is as a cow pat containing a volume of dirt.
2. Faeces transported into the free-stalls on claws (FOOT) — Classification used for manure transported on the cow claws from the alley into the free-stalls. The amount is limited to what follows the claws as a wet foot print.

Cleanliness was scored once for each sector according to the proportion of the area covered with faeces, a method adapted after Gygax et al. (2005):

0. Clean — Stalls without faeces.
1. Almost clean — Less than 25% of the sector was covered with faeces.
2. Some dirt — Between 25 and 50% of the sector was covered with faeces.
3. Dirty — Between 50 and 75% of the sector was covered with faeces.
4. Very dirty — More than 75% of the sector was covered with faeces.

Contamination was ascribed to either FOOT or FAECES, hence only worst case of FOOT or FAECES per sector was registered.

2.7. Statistical analysis

As the contamination of the stalls is mainly located in the rear sectors (E to G), the statistical models were made on the basis of these sectors. The effect of free-stall design on stall cleanliness was estimated in a model in which the factors were categorized by using the quartiles and 10 and 90 percentile groups, for length 0.05 or 0.1 m intervals (Table 1). The variables tested in the model were decided according to the likelihood of having an association to the outcome determined partly according to the literature, and partly on the preliminary hypothesis. The models were constructed at stall sector level using Proc GENMOD (SAS version 9.1. from SAS Institute Inc., Cary, NC, USA) with log link function, binomial distribution with dirty (cleanliness score one to four) or not dirty (cleanliness score 0) as dependent variable using alternating logistic regression according to Carey et al. (1993). Correlation within stall and within herd was taken care of by including stall nested within herd as a random effect. Clustering effect due to the observer was also checked by testing observer as a random effect in the model. The independent variables were analyzed one by one including the cluster effects. The final model was constructed by forward stepwise procedure, adding variables with the lowest initial P-value from the preliminary analyses. For each introduction of a new variable, the results were checked for possible confounding and correlation between fixed effect variables already introduced. Variables with P-values>0.05 was excluded from the model. The goodness of fit was evaluated using delta deviance. The general model used for estimating β was:

$$Logit\ (p_i) = \beta_0 + \beta_1 X_{1is} + \ldots + \beta_k X_{kis} + z_{herd\ (i)} + z_{stall\ (s)}$$

where β_0 is the intercept, $\beta_1 X_{1is} + \ldots + \beta_k X_{kis}$ are fixed effects and $z_{herd\ (i)} + z_{stall\ (s)}$ are random effects due to herd and stall.

Table 1
Stall design factors as used in the models. Categorized factors kept their original classifications, continuous factors were classified in different limits as hierarchical dummy variables, adapted according to median, percentile or quartiles.

Variable	Cut off values for classification (dimensions in meters)
Free-stall length (Wall)	$2.15–2.20^2–2.30–2.35–2.40–2.50^4–2.60–2.70^5$
Free-stall length (Free)	$2.15^2–2.20^3–2.25–2.30^4–2.35–2.40^5–2.45–2.50–2.60$
Stall width	$1.13^2–1.14^3–1.15^4–1.16^5$
Diagonal stall length	$1.84^1–1.88^2–1.92^3–1.96^4–2.00^5$
Rear curb height	$0.15^1–0.20^2–0.24^3–0.28^4–0.31^5$
Upper head rail height	$0.70^1–0.75^2–0.85–0.95–1.00–1.05^4$
Lower head rail height	$0.21^1–0.24^2–0.28^3–0.56^4–0.60^5$
Brisket locator height	$0.05^1–0.08^2–0.10^3–0.15$
Brisket locator length	$1.76^2–1.80^3–1.83^4$
Stall flooring softness [a]	1–2–3–4
Bedding type [b]	1–2–3–4–5
Bedding amount	$0^2–0.5–1^4–2^5–3$ (liter)

[1]10% percentile, [2]25% percentile, [3]median, [4]75% percentile, [5]90% percentile.
[a] 1. Hard base with no or limited cushion. Typical softness: 0 mm. 2. Rubber mats. Typical softness: 4 to 15 mm. 3. Soft mats and mattresses. Typical softness: 16 to 40 mm. 4. Mixed free-stall base. Softness measured as mm impact of a sphere ($d=120$ mm) at 2 kN load.
[b] 1. Sawdust. 2. Straw. 3. Peat. 4. Sand. 5. No bedding used.

3. Results

3.1. Herd characteristics

The average herd size for all visited herds was 38.6 (±14.6) (mean (±SD)) cows within a range of 17.6 to 103.1 cow-years. In all herds the Norwegian Red dairy breed was used as the main breed. The mean shoulder height, measured at third thoracic vertebra, for all cows examined was 1.34 (±0.04) m. There were on average 42.3 (±16.8) stalls per farm and 0.93 (±0.14) cows per free-stall. Mean milk yield per cow-year for the herds visited was 7062 (±945) kg within a range from 3224 to 9249 kg.

3.2. Free-stall design, stall base and bedding

Of the investigated 224 farms, 74.6%, had a barn layout with stalls both against a wall and in single or double rows not against a wall. Respectively, 20.5 and 4.9% of the farms had stalls only against a wall or only stalls not against a wall

Table 2
Free-stall design parameters (mean, standard deviation (SD) and range) for different types identified within 224 dairy farms built between 1995 and 2005. All measures in meter.

Variable	Present in n farms	Mean	SD	Range
Free-stall length–wall [a]	$n=213$	2.39	0.21	2.00–2.80
Free-stall length–free [a]	$n=178$	2.23	0.11	1.90–2.60
Free-stall width	$n=224$	1.14	0.02	1.05–1.20
Neck rail height	$n=224$	1.07	0.05	0.82–1.20
Horizontal Neck rail distance	$n=224$	1.59	0.09	1.25–1.83
Diagonal stall length	$n=224$	1.92	0.07	1.70–2.09
Rear curb height	$n=224$	0.24	0.06	0.04–0.40
Head rail–upper	$n=187$	0.90	0.15	0.52–1.18
Head rail–lower	$n=109$	0.37	0.18	0.08–0.77
Brisket locator length	$n=59$	1.83	0.14	1.60–2.38
Brisket locator height	$n=59$	0.10	0.05	0.02–0.27

[a] At least 167 herds have free stalls both against wall and as double rows (free).

(Table 2). The length of stalls was longer for stalls facing a wall than for stalls in double rows. The width of stalls showed a remarkably small variation. An upper head rail was found in 83.5% of all farms, while 48.7% of the farms had a lower head rail. There was a wide variation in positioning of these rails, especially regarding the lower head rail, but the variation of the upper head rails was also considerable. A brisket locator was used in 59 farms (26.3% of the farms). Rubber mats were more common than respectively soft mats and mattresses (Table 3). Sawdust was the most common type of bedding material recorded for 85.3% of the herds. Sand was used as bedding for two herds and peat for one herd. The mean amount of bedding recorded in all stalls was 0.6 (±1.2) L per stall, whereas the mean amount of bedding material in stalls with sawdust was 0.8 (±1.5) L in sectors B to G. Bedding was not used at all for 13.4% of the herds and less than 0.2 L of bedding was recorded in 44.6% of the stalls.

3.3. Free-stall cleanliness

In total, 23.8% of all the free-stalls were registered as clean (grade 0) for all the seven sectors illustrated in Fig. 1. For the front sectors A to D, more than 98% were found without any FAECES contamination (FAECES score 0) and more than 93% of the sectors were without any FOOT contamination (FOOT score 0) (Tables 4 and 5). The stalls were most contaminated in the three rear sectors (E to G). As an overall observation from Tables 4 and 5, FOOT contamination was significantly more frequent compared to FAECES with 13.5 [12.4–14.6] versus 7.6 [6.7–8.5] % of the sectors being contaminated (95% CI in [ ]). However, FAECES had generally a higher score than FOOT.

3.4. Effect of free-stall design on stall cleanliness

No random effect of observer was found in the statistical analyses. Associations of free-stall design parameters on either FAECES or FOOT are presented in Tables 6 and 7.

Stalls recorded with a quantity of bedding in sectors B to G higher than 1.0 L had a lower risk of being FAECES contaminated than stalls with 0.2 to 1.0 L and especially stalls without bedding in the same sectors. For concrete floors the risk of being FOOT contaminated was lower than for softer stall bases when using an amount of bedding equal to or less than 0.5 L per stall (Fig. 3), which means that the use of bedding was more effective on concrete than on softer stall base. There was a lower risk of being FAECES contaminated when the diagonal distance of the neck rail position was equal to or less than 1.96 m, whereas the diagonal distance had no effect on FOOT contamination. Absence of a lower head rail was associated with a lower FAECES score, but had no effect on FOOT score. Short stalls located against wall were found to have a lower risk of being FAECES contaminated than longer stalls, whereas no effect of stall length in double rows was found. Stall length had no effect on FOOT score in any stall type. Stalls with a brisket locator located at a distance equal to or less than 1.83 m from the rear curb had a lower risk of being FAECES contaminated but had no effect on FOOT contamination. Stalls with a brisket locator equal to or lower than 0.1 m had a lower risk of being FOOT contaminated while no effect was found on the FAECES score. Stalls equal to or narrower than 1.13 m in width had a higher risk of being FAECES contaminated, whereas stalls equal to or narrower than 1.13 m had a lower risk of being FOOT contaminated. Free-stalls with an upper head rail located equal to or lower than 0.7 m above the stall surface had a higher risk of being FAECES contaminated and stalls with an upper head rail located equal to or lower than 1.0 m had a higher risk of being FOOT contaminated. Concrete stall bases had a lower risk of being FOOT contaminated than other stall base softness groups. Type of free-stall base had no effect on FAECES score, whereas height of the rear curb had no effect on either FAECES or FOOT score. There is an increased risk for lateral stall sections to be contaminated with FAECES, whereas the middle sections are likely to be contaminated with FOOT.

Table 3
The distribution of stall base and types of bedding in 224 free-stalled herds as % of the total number of herds.

	Concrete	Rubber	Soft mats and mattresses	Mix	Total
Sawdust	2.2	42.9	31.7	8.5	85.3
Straw	0.0	0.0	0.0	0.0	0.0
Sand	0.0	0.4	0.0	0.4	0.9
Peat	0.0	0.0	0.4	0.0	0.4
No bedding used	0.9	7.6	4.9	0.0	13.4
Total	3.1	50.9	37.1	8.9	100.0

Table 4
The distribution of contamination in free stall sectors A to G in 3,459 free-stalls within 224 dairy herds assessed as faeces deposited on the stall base (FAECES).

Sector	0 [a]	1 (<25%)	2 (25–50%)	3 (50–75%)	4 (>75%)
A (front)	99.7	0.2	0.1	0.0	0.0
B (middle)	98.7	1.1	0.1	0.1	0.0
C (middle)	99.4	0.5	0.1	0.0	0.0
D (middle)	99.2	0.6	0.1	0.1	0.0
E (rear)	78.8	12.3	6.0	2.1	0.8
F (rear)	89.6	7.1	2.5	0.7	0.1
G (rear)	81.5	10.8	4.6	2.3	0.8
Mean	92.4	4.7	1.9	0.8	0.2

[a] 0 is “clean” stalls, 4 is “very dirty”. The percentage in brackets reflects the soiled proportion of each sector.

Table 5
The distribution of contamination in free stall sectors A to G in 3,459 free-stalls within 224 dairy herds assessed as faeces deposited as wet foot prints on the stall base (FOOT).

Sector	0 [a]	1 (<25%)	2 (25–50%)	3 (50–75%)	4 (>75%)
A (front)	98.8	1.1	0.0	0.1	0.0
B (middle)	95.6	4.2	0.2	0.0	0.0
C (middle)	93.2	6.0	0.7	0.1	0.0
D (middle)	95.9	3.8	0.3	0.0	0.0
E (rear)	78.4	18.6	2.4	0.5	0.1
F (rear)	66.5	28.0	4.4	1.0	0.1
G (rear)	77.1	19.7	2.6	0.5	0.1
Mean	86.5	11.6	1.5	0.3	0.04

[a] 0 is “clean” stalls, 4 are “very dirty”. The percentage in brackets reflects the soiled proportion of each sector.

Table 6
The model based estimates with standard error (SE) for significant free-stall design parameters in the final logistic model[a] for contamination caused by faeces deposited in the free stalls (FAECES). Statistical unit in the model was $n = 10,377$ stall sectors with 3 sectors per stall.

Variable	Herds and stalls, *n*/*n*	Class	Estimate	SE estimate	OR[b]	OR[b] 95% CI	*P*
Intercept	224/3,459		−2.247	0.211	—	—	
Sector	224/3,459	E (left rear)	0.862	0.069	2.37	2.07–2.71	<0.001
	224/3,459	F (middle)	0.000	0.000	1.00	1.00	.
	224/3,459	G (right rear)	0.679	0.068	1.97	1.73–2.25	<0.001
Bedding amount, L[c]	155/1,524	0	0.687	0.125	1.99	1.55–2.54	<0.001
	177/1,408	0.2–1	0.351	0.123	1.42	1.12–1.81	<0.005
	78/527	≥1	0.000	0.000	1.00	1.00	.
Diagonal stall length, m	170/2,643	≤1.96	−0.515	0.125	0.60	0.47–0.76	<0.001
	54/816	>1.96	0.000	0.000	1.00	1.00	.
Lower head rail	115/1,792	Not present	−0.508	0.136	0.60	0.46–0.79	<0.001
	109/1,667	Present	0.000	0.000	1.00	1.00	.
Stall length, m	79/1207	Wall: <2.30	−0.412	0.144	0.66	0.50–0.88	<0.005
	64/971	Wall:2.30–2.45	−0.299	0.145	0.74	0.56–0.98	<0.05
	70/1,114	Wall: >2.45	0.000	0.000	1.00	1.00	.
	11/167	Dbl. row only	−0.489[NS]	0.323	0.61	0.33–1.15	0.130
Brisket locator distance, m	59/2,532	Not present	0.335	0.164	1.40	1.01–1.93	<0.05
	45/717	≤1.83	0.000	0.000	1.00	1.00	.
	14/210	>1.83	0.680	0.256	1.97	1.19–3.25	<0.01
Stall width, m	80/1,259	≤1.13	0.283	0.107	1.33	1.08–1.63	<0.01
	144/2,200	>1.13	0.000	0.000	1.00	1.00	.
Upper head rail, m	37/559	Not present	0.299[NS]	0.169	1.35	0.97–1.88	0.077
	19/295	≤0.70	0.392	0.180	1.48	1.04–2.11	<0.05
	168/2,605	>0.70	0.000	0.000	1.00	1.00	.
Alpha 1 (stall)	224/3,459	–	1.154	0.085	3.17	2.68–3.74	<0.001
Alpha 2 (herd)	224/3,459	–	0.382	0.061	1.47	1.30–1.65	<0.001

[NS] indicates non-significant *P*-value of actual parameter ($P>0.05$).
[a] Binomial distribution; contaminated or not (0 versus 1, 2, 3 or 4) and with stall nested within herd included as random effect.
[b] Odds Ratio (OR) with 95% confidence interval (95% CI) is included.
[c] Total sum is larger than number of farms as more than one class of bedding is represented on each farm.

Table 7
The model based estimates with standard error (SE) for significant free-stall design parameters in the final logistic model[a] for contamination caused by faeces deposited as wet foot prints in the free stalls (FOOT). Statistical unit it the model was $n = 10,377$ stall sectors with 3 sectors per stall.

Variable	Herds and stalls, *n*/*n*	Class	Estimate	SE estimate	OR[b]	OR[b] 95% CI	*P*
Intercept	224/3459		−2.446	0.451	–	–	<0.001
Sector	224/3459	E (left rear)	−0.628	0.060	0.53	0.47–0.60	<0.001
	224/3,459	F (middle)	0.000	0.000	1.00	1.00	.
	224/3,459	G (right rear)	−0.543	0.057	0.58	0.52–0.65	<0.001
Bedding amount[d], L	208/2,559	≤0.5	1.724	0.344	5.61	2.86–11.00	<0.001
	108/900	>0.5	0.000	0.000	1.00	1.00	.
Stall base softness[c]*bedding amount[d]	5/49	1. ≤0.5	0.000	0.000	1.00	1.00	.
	6/63	1. >0.5	0.000	0.000	1.00	1.00	.
	109/1,346	2. ≤0.5	0.000	0.000	1.00	1.00	.
	47/363	2. >0.5	−1.080	0.363	0.34	0.17–0.69	<0.005
	78/986	3. ≤0.5	0.000	0.000	1.00	1.00	.
	44/340	3. >0.5	−1.188	0.370	0.30	0.15–0.63	<0.002
	15/178	4. ≤0.5	0.000	0.000	1.00	1.00	.
	12/134	4. >0.5	−0.769[NS]	0.437	0.46	0.20–1.09	0.078
Brisket locator height, m	165/2532	Not present	−0.154[NS]	0.179	0.86	0.60–1.22	0.39
	39/613	≤0.10	−0.502	0.190	0.61	0.42–0.88	<0.01
	20/314	>0.10	0.000	0.000	1.00	1.00	.
Upper head rail, m	33/559	Not present	0.188[NS]	0.159	1.21	0.88–1.65	0.24
	191/2,900	≤1.00	0.388	0.150	1.47	1.10–1.98	<0.01
	191/2,900	>1.00	0.000	0.000	1.00	1.00	.
Stall base softness	7/112	1. Concrete	0.000	0.000	1.00	1.00	.
	114/1,709	2. Rubber	1.432	0.436	4.19	1.78–9.85	<0.001
	83/1,326	3. Mattress	1.333	0.456	3.79	1.55−9.27	<0.005
	20/312	4. Mix	1.120	0.472	3.06	1.22−7.73	<0.02
Stall width, m	80/1,259	≤1.13	−0.246	0.108	0.78	0.63−0.97	<0.05
	144/2,200	>1.13	0.000	0.000	1.00	1.00	.
Alpha 1 (stall)	224/3459	—	0.581	0.077	1.79	1.54−2.08	<0.001
Alpha 2 (herd)	224/3459	—	0.460	0.053	1.58	1.43−1.76	<0.001

[NS]indicates non-significant *P*-value of actual parameter ($P>0.05$).
[a] Binomial distribution; contaminated or not (0 versus 1, 2, 3 or 4) and with stall nested within herd included as random effect.
[b] Odds Ratio (OR) with 95% confidence interval (95% CI) is included.
[c] The coding for stall base softness is 1 = concrete, 2 = rubber, 3 = mattress and 4 = mixed.
[d] Total sum is larger than number of farms as more than one class of bedding is represented on each farm.

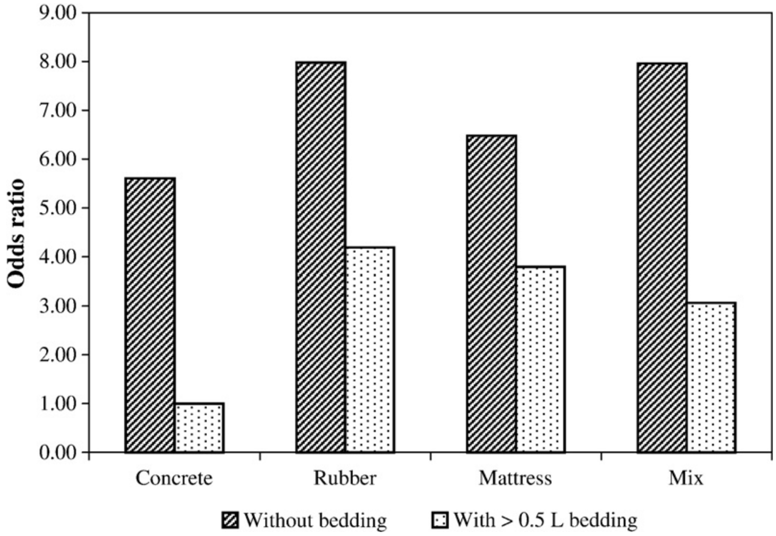

Fig. 3. The interaction effect of free-stall base softness (concrete, rubber, mattress or mix) and bedding (≤0.5 or>0.5 L sawdust per stall) on stall cleanliness shown as odds ratio (n = 10,377 stall sectors). The figure is based on faeces transported into the free-stalls on cow claws.

4. Discussion

4.1. Free-stall design and bedding

In most farms in this study, mean free-stall length against a wall was in accordance with Norwegian regulations (Norwegian Food Authorities, 2004), recent US recommendations (McFarland, 2003) and international recommendations (CIGR, 1994), but shorter than recommended by Anderson (2008). The free-stall length in a double row was longer than Norwegian regulations, international recommendations and US recommendations, but shorter than recommended by Anderson (2008). The position of the lower head rail was higher than recommended (Norwegian Cattle Health Services, 2005). Cows of the Norwegian Red dairy breed are smaller than Holstein cows, explaining why smaller stall sizes are used in Norway. It is worrying that nearly 45% of the stalls were recorded without bedding material, considering its importance for stall hygiene, animal hygiene (Nygaard, 1979; Herlin et al., 1994) and comfort (Tucker et al., 2004).

4.2. Level of contamination

As an overall observation the stalls were quite clean, and as expected the rear sectors were the most contaminated, as also found by Gygax et al. (2005). The mid-sectors were most at risk for FOOT contamination whereas the side sectors were most at risk of being FAECES contaminated. To our knowledge, surprisingly few studies have focused on free-stall cleanliness, and despite the study of Gaworski et al. (2003) who used a detailed grid of small squares to determine the degree of soiling, these studies have used simplified methods for characterizing stall cleanliness (Herlin et al., 1994; Tucker et al., 2005; Gygax et al., 2005).

4.3. Effect of free-stall design on stall cleanliness

Interestingly, the length of the stall had no effect on FOOT stall cleanliness, probably because it is the head and neck rails that determine the space that is accessible lengthwise and hence limit the freedom of movement of the animal. However, the effect of stall length on FAECES cleanliness could be caused by cows defecating when standing diagonally or lying in stall in accordance with Gygax et al. (2005) that found larger stalls to be more contaminated.

In the present study, a restrictive diagonal position of the neck rail had a positive effect on stall cleanliness, which is in accordance with the results of Tucker et al. (2005). However, it is interesting to note that a diagonal length of the neck rail shorter than 1.96 m was associated with improved stall cleanliness, whereas presence of a lower head rail, narrow stalls and a forward-positioned brisket locator had a negative influence on stall cleanliness (FAECES) in our study. Both head rails will probably interfere with the standing up and lying down movements of the cow as shown by Cermak (1988) and McFarland and Graves (1995). Behaviour involving more frequent standing up and lying down is also shown to be connected with more frequent defecation (Aland et al., 2002), which may increase the possibility for the cow to contaminate the stall. Tucker et al. (2005) reported that a large proportion, of the relatively few defecations occurring in the stall, occurred while the cows were lying down; hence a better understanding of this behavior may be useful to improve stall design and to keep the stalls cleaner. Thus, some of the limitations in the stall design intended to restrict the animal's movements in order to improve animal cleanliness, can actually result in the opposite. One could thereby hypothesise that the cows are possibly stressed by these limitations, leading to more contamination. This could be a subject in future research. A brisket locator had a positive impact on stall cleanliness and thus should be included in future free-stall design where clean stalls are the aim. As opposed to FAECES contamination, the free-stall design had little influence on FOOT contamination and it seems reasonable to expect a dirty alley to be more important for FOOT cleanliness. Magnusson et al. (2008) found that the more the floor in the alley was soiled the greater the risk for free-stall contamination. In the present study, a narrow stall contributed to cleaner conditions regarding FOOT contamination, whereas the opposite was found concerning FAECES contamination. The effect of stall width on FOOT contamination can be explained by narrower stalls restricting the cow's position when walking into the stalls and thus resulting in a more concentrated deposition of faeces. Interestingly, stall base softness had no influence on FAECES stall cleanliness, while a major influence of bedding material was found where even a minor amount of sawdust is better than nothing to improve stall cleanliness. Furthermore, bedding is not only a means for comfort or hygiene (e.g. Tuyttens, 2005). It is also preferred by the animals even on top of a soft free-stall base (Tucker and Weary, 2004). As a closing remark, there has been an interesting development in free-stall design (Tillie, 1986) from the short and more enclosed free-stalls in Major Bramley's 1957 shed to today's modern design with open stalls providing the cows with greater freedom of movement.

4.4. Statistical methods

The stall cleanliness was recorded in seven different sectors, where only three (the rear sectors) had so much dirt that it made any sense to analyze the variation between stalls and barns. These three sectors (left, middle and right) were analyzed included as fixed effects while stall was included as random effect nested within herd. The fixed effect will present the mean difference between the different sectors in the stall, which was found different between middle and side and also between left and hind. As each sector also could be seen as a repeated observation within each stall, this repeated stall effect was included as random effect nested within herd in the model. The random effect presents the correlation between different sectors within the same stall, as the random effect of herd present the correlation between different stalls within the same herd. This will give maximum information of the material. In the statistical analyses repeated measurements with the same number of stalls per farm were used, in this way all farms were equally represented in the study. Using a cluster analysis takes care of the dependency between observations within the stall and within the same farm. No random effect of observer was found in the statistical analyses as clustering effect due to observer was analyzed by testing observer as a random effect in the model, hence the possibility for having an erroneous effect due to observer is less than 5%.

A simpler model could be made by using the mean of the three rear stall sectors for each stall in the models, but in this way information and correlation between sectors would be lost. One could also analyze each sector separately in separate models. Nevertheless, the answers based on these models would not be comparable, they would include a smaller dataset and the correlation between them would be unknown.

5. Conclusions

Use of bedding as well as a stall design with rails located so that the raising and lying down movements of the cow is not restricted too much, is associated with cleaner stalls. This indicates that the lower head rail should be removed and the upper head rail should be positioned at least 0.7 m, possibly as high as 1.0 m, above the stall base. Further, a brisket locator being maximum 0.1 m high and located 1.83 m from rear curb was associated with clean free-stalls.

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Paper III

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Risk factors for dirty dairy cows in Norwegian freestall systems

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ABSTRACT

Cow cleanliness is important for ensuring hygienic milk production and the well-being of dairy cows. The aim of this cross-sectional field study was to describe cow cleanliness in freestall-housed dairy herds and to examine risk factors related to thigh cleanliness. Cow cleanliness (n = 2,335), management-related variables (e.g., ventilation and use of sawdust-bedded stalls), and housing-related variables (e.g., freestall design and number of cows per stall) were recorded in 232 Norwegian freestall-housed dairy herds. Cleanliness was scored on a 4-point scale ranging from clean (1) to very dirty (4). The cows were relatively clean on the udder and belly, dirtier on thigh and the rear part of the body, and dirtiest on the legs, with cleanliness scores (mean ± SD) of 1.64 ± 0.62, 1.62 ± 0.65, 2.02 ± 0.75, 1.77 ± 0.58, and 2.30 ± 0.59, respectively. With dirty thighs as the response variable, several variables were tested in a logistic regression mixed model and with repeated measurements within herd and cow. A high number of cows per freestall [odds ratio (OR) = 3.45], no use of sawdust as bedding (OR = 3.24) versus use of sawdust, and a low-positioned (<0.85 m above stall floor) upper head rail "enclosing" the front of the stall (OR = 1.42 to 2.13) versus a position >0.85 m were all risk factors for dirty thighs on the cows. Furthermore, liquid manure (score 2) versus more consistent manure (score 1; OR = 1.66) and less tame cows (score 2) versus tame cows (score 1) were associated with an increased risk of dirty thighs (OR = 1.24). The cleanest cows were associated with indoor temperatures in the range from 10 to 15°C. For each 10-percentage-unit increase in relative air humidity, the risk of dirty thighs increased (OR = 1.32). Freestalls with a construction hindering normal lying, rising, and standing movements should be avoided. Furthermore, focus is needed on indoor climate and manure consistency to obtain cows with clean thighs.

Key words: cow cleanliness, thigh cleanliness, freestall

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INTRODUCTION

The cleanliness of the cows is important for obtaining hygienic milk production, ensuring the well-being of the cows, and sustaining udder health in the herd (Schreiner and Ruegg, 2003; Munoz et al., 2008; Breen et al., 2009). The degree of cleanliness of the cow influences thermoregulation and hygiene at the time of slaughter: the dirtier the cow the greater the heat loss and the greater the danger to hygiene in the abattoir. The legs, belly, and thighs are usually the most contaminated body parts of animals housed in freestalls, whereas udders are normally cleaner because of being cleaned daily in connection with milking (Veissier et al., 2004; Reneau et al., 2005).

Methods for assessing cow cleanliness include some kind of subjective assignment into categories according to predefined criteria (Schreiner and Ruegg, 2003). Some studies used simplified methods assessing animal cleanliness if at least a given area of the body was contaminated (Hultgren and Bergsten, 2001), whereas others used a more fine-tuned scale; for example, from clean to very dirty (Schreiner and Ruegg, 2003; Gygax et al., 2007). Body parts (e.g., leg, thigh, and udder) are normally recorded separately. Interestingly, the original basis for the invention of the freestall was the problem of cleanliness (Bramley, 1962), and Schmisseur et al. (1966) confirmed that freestall housing kept cows cleaner and reduced bedding requirements compared with traditional loose housing. Between farms with similar systems, variation exists in cow cleanliness because of differences in housing design and management. In a survey by Veissier et al. (2004), a higher number of cows per stall tended to be associated with the cows being dirtier. Udder cleanliness, assessed as teat-end bacterial count, was worse if the stall was dirty (Zdanowicz et al., 2004). Regarding stall design, the length and width of the stall, together with the position of neck and head rails, were important for freestall cleanliness (Tucker et al., 2005; Fregonesi et al., 2009). Previous findings show that properties of the lying surface, as well as use of bedding, influence cattle cleanliness (Herlin, 1997; Fulwider et al., 2007; Norring et al., 2008). A dirty alley may lead to contamination of the cows as manure can be splashed directly on to the animals or can be transported into the stalls on the claws of cows (L. E. Ruud; unpublished data). Magnusson et al. (2008) found an association between the amount of manure in the alley and cleanliness of the udder and teats, where the frequency of scraping was important for cow cleanliness. Knowledge on the effects of tameness on cow cleanliness seems scarce. Kilgour (1975), in an open-field test where the cows were classified for temperament by the milker, claimed that easily scared cows urinated and defecated more frequently. The associations between test variables in this type of test are often difficult to interpret, and the direct link to manure consistency was not an objective of the study. Despite these problems, an open-field test is a useful measure of responses to fear or stress (Waiblinger et al., 2003). Furthermore, the dirtiness of the animals is usually considered a long-term effect of housing and management. Thus, factors such as the barn layout, indoor climate, feeding regimen, the management itself, and access to mechanical brushes may influence cattle cleanliness. The objective was to describe cow cleanliness in Norwegian freestall-housed dairy herds and to examine risk factors regarding housing and management variables associated with cow cleanliness.

MATERIALS AND METHODS

The Herds

This study was part of a larger descriptive and cross-sectional project on freestall housing, in which the selection of herds concerned the entire project. From a questionnaire to all dairy consultants in Norway, we obtained a list of 2,400 dairy herds that were presumed housed in freestalls. All these farmers received a questionnaire covering several aspects of their freestall housing system; for example, age of the housing system, loose housing, or tie stalls. To be included in the study, the farmers had to fulfill the inclusion criteria: volunteering to participate, barns built 1995 to 2005, and herd size >20 standardized cow-years based on the year 2005 (cow-year = sum of number of days within a herd from first calving to culling within 1 yr, divided by 365; this corresponded to mean number of cows in the herd at any time). All farms with robotic milking (n = 44), with solid concrete floors (n = 80) or solid rubber floors (n = 16) in the alleys were included. From the initial phase of the freestall project, the distribution of floor types in the alleyways was approximately 80% slatted concrete floors, 18% solid concrete floors, and 2% solid rubber floors. Herds on slatted floors fulfilling the inclusion criteria were included only if they were located in the same municipality as farms with robotic milking or solid floors mentioned above. Hence, herds on solid concrete floors or rubber in the alleys were overrepresented compared with the total population. Therefore, this study is not a random study, but a cross-sectional descriptive study with random selection within groups (e.g., cows and stalls). The total material used consisted of 232 freestall-housed dairy herds located all over Norway.

Cleanliness Observations

During the indoor feeding period from September 2006 until May 2007, 232 herds were visited once by 1 of 5 trained observers, and several housing- and management-related variables were recorded. To standardize the data collection, an initial 2-d training session followed by 3 additional training sessions during the recording period was performed. Two of the observers conducted the majority of the assessments (73%) and had regular meetings between farm visits to enhance the consistency in data recording. A systematic protocol was used to record data on each farm. Additionally, data were analyzed for significant clustering effects of observer to ensure no significant differences in recording. On each farm, 10 cows were subjected to cleanliness observations. According to their unique ID number, the cows were randomly chosen by selecting every second, third, et cetera, cow, depending on the herd size (n cows/10 and then closest integer). Cow cleanliness was scored for 2,335 cows in the 232 herds following a scheme adapted from Schreiner and Ruegg (2003) by using a 4-point scale: 1 = clean, 2 = some dirt, 3 = dirty, or 4 = very dirty with caked-on dirt. Udder, belly, leg, thigh, and rear were assessed separately for cleanliness (Figure 1). Mean total cleanliness score was calculated per cow by adding together the scores for the different body parts; hence, a score of 5 indicated a totally clean cow and a score of 20 indicated a cow totally covered in dirt. Only risk factors for dirty thighs (for both the left and the right side) were analyzed in a full statistical model and reported in this paper. This was decided after checking the output, as cleanliness score for thigh was most correlated to the cleanliness score for the other body parts (Table 1). Thigh cleanliness described total cow cleanliness to a certain degree. Furthermore, dirty thighs (score 2 to 4) were most prevalent, after dirty legs. Magnusson et al. (2008) showed that leg cleanliness was more associated with flooring in the alley rather than other housing variables.

Fixed Factors

For each farm, 50 relevant housing and management variables (Table 2) were recorded and tested in the

Table 1. Correlation between cleanliness observations based on the body parts: leg, thigh, udder, belly, and the rear part of the body for cows (n = 2,335) in 232 Norwegian freestall-housed dairy herds

	Rear	Thigh	Leg	Udder
Thigh[1]	0.39			
Leg[1]	0.27	0.46		
Udder[1]	0.32	0.45	0.34	
Belly[1]	0.24	0.45	0.38	0.37

[1]P-values for all correlations in the matrix <0.001.

statistical model. Only the most relevant variables are described in detail here.

Freestall Design. The variables recorded were freestall length and width, neck and head rail positions, rear curb height, brisket board height and location (brisket board found in n = 59 herds), slope of stall base against rear curb, and freestall base softness (scored as concrete, rubber, mattress, or mixed floorings).

Barn Layout and Cow Density. Barn layout was recorded as number of freestall rows and number of dead-end alleys (alley length >2 m and narrower than 3 m). In addition, the numbers of cows and stalls in the main group of milking cows were recorded.

Climate. Relative air humidity (**RH**) and air temperature (°C) were measured 1.5 m above the floor at the center of the feed bunk using a digital hygrometer (Kimo HD 100, Kimo Instruments, Montpon, France; www.kimo.fr).

Manure Consistency. Manure consistency, adapted from Hughes (2001) and Hulsen (2005), in the alleys was assessed by the observers slowly walking in the alley: 1 = dry, not smeared cow pats, 2 = dung smeared, but the observer's boot print remains distinct, 3 = dung smeared and flat, and the observer's boot print disappears, and 4 = liquid pools of feces ("water like").

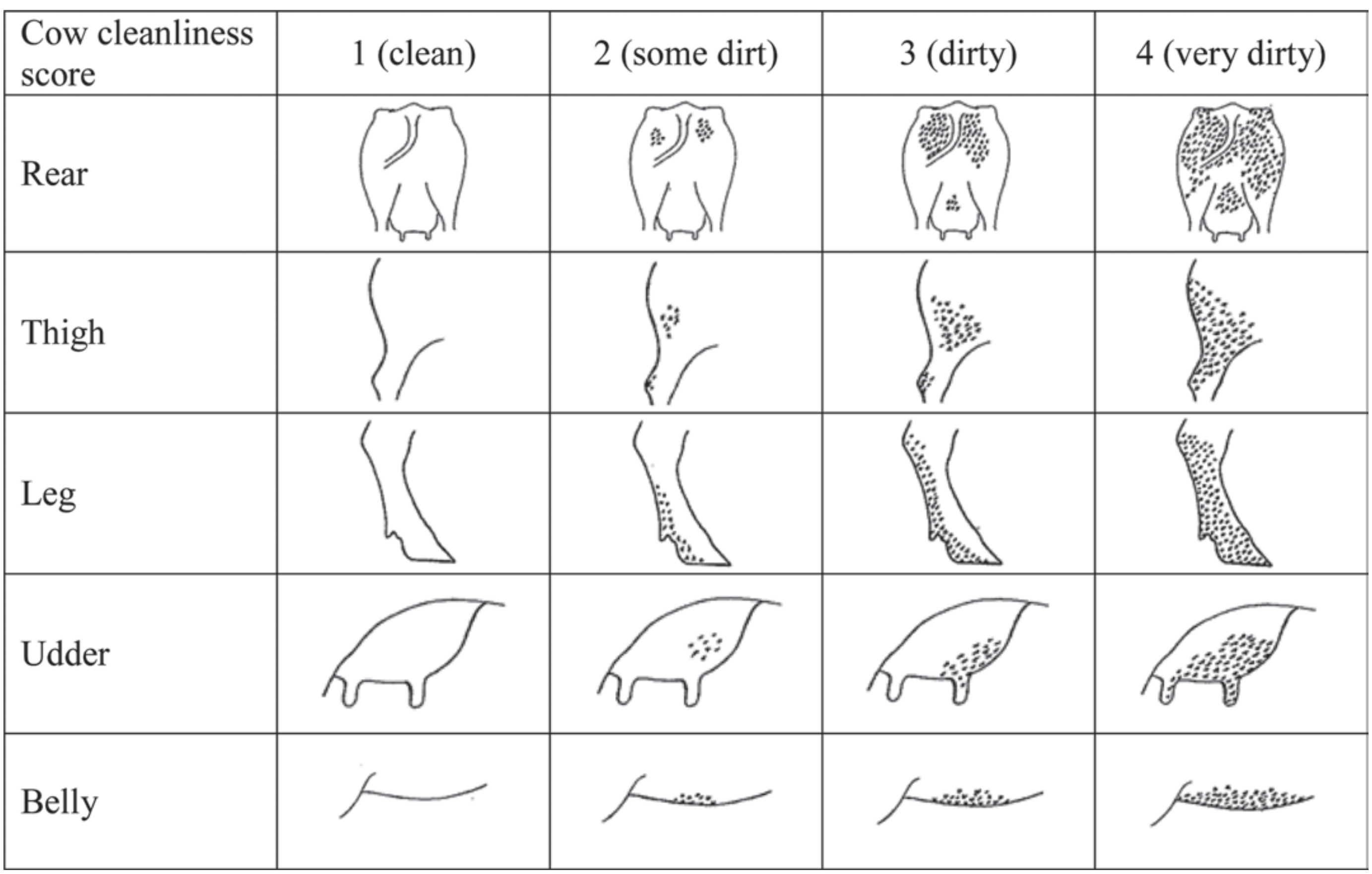

Figure 1. Scheme for cow cleanliness scoring on the rear, thigh, leg, udder, and belly, where 1 = clean, 2 = some dirt, 3 = dirty, and 4 = very dirty.

Management Factors and Cow Tameness. Number of brushes (mechanical, nonmechanical, or no brushes) in the main group of milking cows, as well as type (sawdust, straw, sand, turf, or no bedding) and amount of bedding were recorded. The amount (volume) of bedding in the 1.2 m closest to the rear curb of the stall was recorded by gently removing the bedding material into a 5-L container with a liter scale. Cow tameness (adapted from Waiblinger et al., 2003) was assessed in a simple avoidance test where the technician slowly (approximately 0.5 step per second) approached the same animals as those being assessed for cleanliness: 1 = touchable cow that does not move away; 2 = barely touchable with fingertips; 3 = stays out of reach, but within 2 to 3 m; 4 = stays far away, >3 m.

Statistical Analysis

When making a model with many independent variables, one problem is how to reduce the number of

Table 2. Housing and management related variables evaluated before running the full statistical model

Variable	Class and unit
Freestall length wall	Continuous, m
Freestall length double row	Continuous, m
Neck rail height	Continuous, m
Horizontal neck rail distance	Continuous, m
Diagonal distance neck rail	Continuous, m
Stall width	Continuous, m
Upper head rail height	Continuous, m
Lower head rail height	Continuous, m
Rear curb height	Continuous, m
Brisket board height	Continuous, m
Brisket board length	Continuous, m
Slope of stall base, wall	Continuous, m
Slope of stall base, double row	Continuous, m
Amount of bedding	Continuous, L
For slatted floors; slat width	Continuous, m
For slatted floors; slot width	Continuous, m
Alley width	Continuous, m
Number of cows	n
Number of cow years	n
Number of stalls	n
Cows per stall	n
Number of rows with stalls	n
Number of pens with milking cows	n
Number of drinking places	n (single waterers = 8 drinking places; 0.1 m trough = 1 place)
Number of cows per drinking place	n
Cow tameness	Touchable not moving away, barely touchable, stays out of reach but <2–3 m, stays far away (>3 m)
Manure consistency in alley against feed bunk	1 = firm, standing cow pats, 4 = water-like
Scraping routines stalls	All stalls daily, on demand, never
Scraping routines alley	n per day
Brushing	Daily, on demand, never
Type of brushes	Manual, mechanical, nonmechanical, none
Mechanization of roughage feeding	Manual, feed trolleys, mechanical, automatic
Silage or TMR	Silage, TMR
Doors in concentrate feeders?	Yes, no
Type of neck rail	Pipe, strap, wood, none
Brisket board?	Yes, no
Number of lesions, neck hock and legs	Number of hairless spots and larger
Locomotion score	1 to 5
Body condition score	1 to 5
Building	Insulated, noninsulated
Air temperature	°C
Relative humidity	RH%
Air velocity	m/s
Lighting	lx
Freestall base softness	Concrete, rubber, mattress, mix
Type of bedding	Sawdust, straw, turf, sand, none
Shoulder height	Continuous, m
Type of alley floor	Slatted, solid, rubber, asphalt
Friction in alley	4 classes
Milk yield / cow year	kg

Table 3. Distribution of contamination (%) on legs, thighs, rear, udder, and belly of dairy cows (n = 2,335) in 232 Norwegian freestall-housed dairy herds

	Contamination score			
Contamination, %	Clean (1)	Some dirt (2)	Dirty (3)	Very dirty (4)
Leg[1]	6.3	72.1	18.7	2.9
Thigh[1]	35.1	48.1	14.0	2.8
Rear[2]	30.6	62.3	6.7	0.4
Udder[1]	56.8	38.5	4.4	0.3
Belly[1]	59.5	35.3	4.2	1.0

[1]Based on individual mean value for evaluation on both sides of the body.

[2]One observation per cow.

descriptive variables to a number that will work in a regression model. Regardless of how this is performed, one loses potentially useful explanation variables in the final model. Fifty variables of interest remained after removing variables without interest logically or biologically, such as width of feeding alley and claw care routines. To reduce this number in the final model, all variables were first tested against thigh cleanliness score using PROC CORR in SAS (SAS version 9.1; SAS Institute Inc., Cary, NC). According to the principle of Bonferroni, only variables with P-value ≤ 0.001 (P-value of 0.05/n factors) in the correlation outcome were used, being introduced one by one into the final model using a forward stepwise procedure, and ranked according to degree of correlation with thigh cleanliness. Continuous factors were categorized by using the quartiles and 10 and 90 percentile groups. The final model was constructed with thigh as the statistical unit using PROC GENMOD (SAS version 9.1. from SAS Institute Inc.), with log link function, binomial distribution with clean (cleanliness score 1) or dirty (cleanliness score 2 to 4) as dependent variables. The regression was performed using alternating logistic regression according to Carey et al. (1993), and taking care of the correlated and repeated observation of thigh cleanliness within herd and cow by including cow as a subcluster nested within herd as subject in the repeated effect statement applying the logor option. For each introduction of a new variable, the results were checked for possible confounding and correlation between fixed effect variables already introduced. Variables with P-values >0.05 were excluded from the model. The goodness of fit was evaluated using delta deviance. The general model used for estimating β was

$$\text{Logit } (p_i) = \beta_0 + \beta_1 x_{1ic} + \ldots + \beta_k x_{kic} + z_{herd(i)} + z_{cow(c)},$$

where β_0 is the intercept, $\beta_1 x_{1ic} + \ldots + \beta_k x_{kic}$ are fixed effects, and $z_{herd(i)} + z_{cow(c)}$ are random effects due to herd and cow. β_1 to β_k are regression coefficients corresponding to the independent explanatory variables x_1 to x_k. Clustering effect due to observer was checked by testing observer as a random effect in the model.

RESULTS

Herd Characteristics

The average herd size for the farms visited was 38.6 ± 14.6 (mean ± SD) cow-years with a range of 17.6 to 103.1. Norwegian Red dairy breed was the main breed (98.8%). The shoulder height, measured at third thoracic vertebra, was 1.34 ± 0.04 m with a range from 1.19 to 1.50 m. Milk yield per cow year for the herds visited was 7,062 ± 945 kg, ranging from 3,224 to 9,249 kg. All herds except 2 had only 1 group of milking cows.

Cow Cleanliness

The percentages of body parts scored as clean (1) were approximately 60% on both belly and udder, 35 and 31% on thigh and rear, respectively, and only 6% on legs (Table 3). A very low proportion of the cows scored very dirty (4). Mean cleanliness scores, assuming a continuous scale, were 2.30 ± 0.59 for legs, 2.02 ± 0.75 for thighs, 1.77 ± 0.58 for the rear, 1.64 ± 0.62 for udder, and 1.62 ± 0.65 for the belly. Wide variation existed between herds in cleanliness (Figure 2). The total cleanliness score was 8.73 ± 2.10, ranging from 5 to 19. In total, 31 cows (1.3%) had a total cleanliness score of 5 (meaning totally clean), 1,874 cows (80.3%) had a score ≤10, and 2,288 cows (98.0%) had ≤15.

Housing and Management Variables

There were 42.3 ± 16.8 stalls in the herds, averaging 0.93 ± 0.14 cows per stall. Floors in the alley in the selected 232 farms were 57.3% slatted concrete floors, 34.5% solid concrete floors, and 6.9% solid rubber

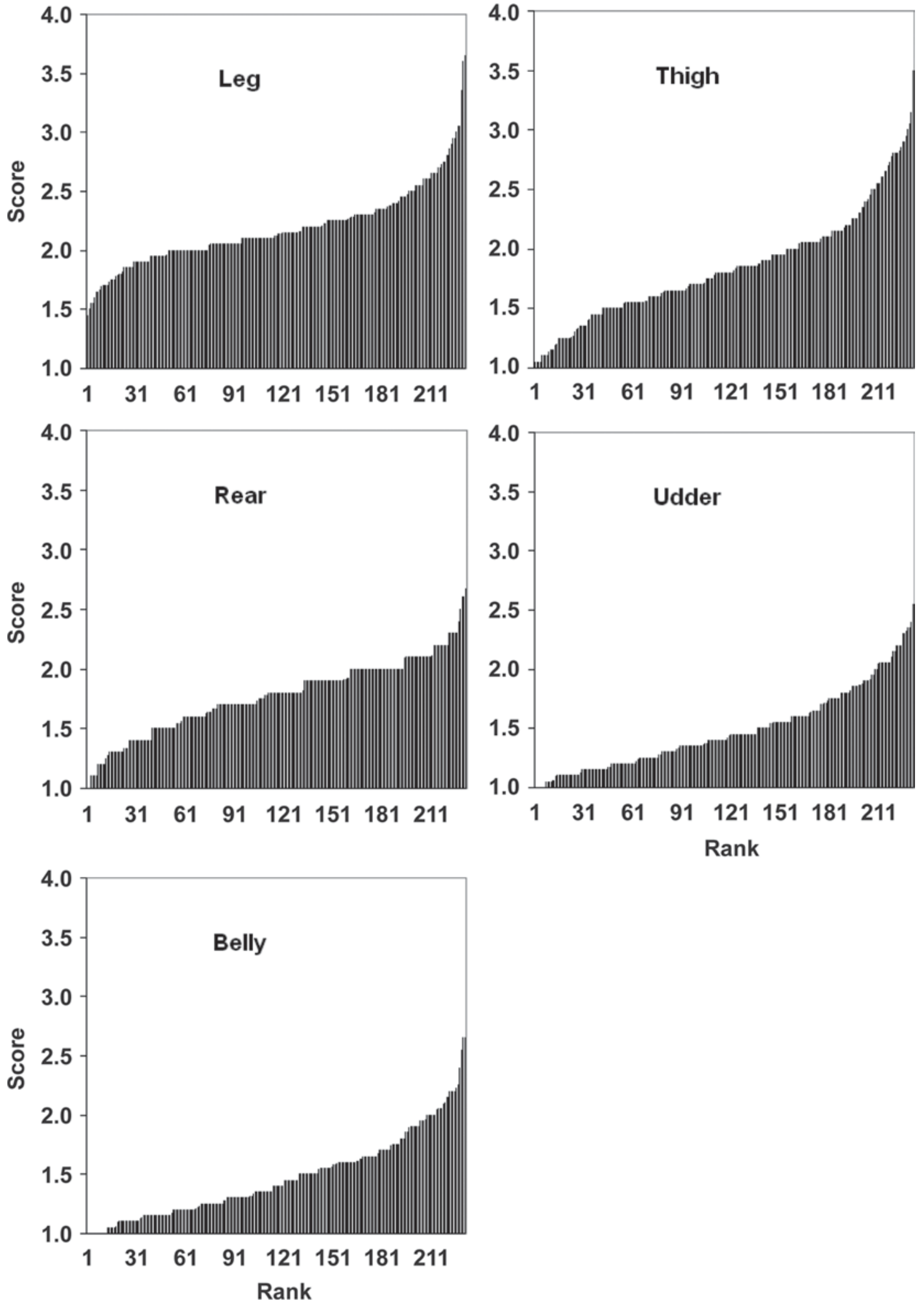

Figure 2. Mean cleanliness score (y-axis) for each herd for the body parts: leg, thigh, udder, belly, and the rear part of the body. Each body part was scored from 1 (clean) to 4 (very dirty). The illustration is at herd level and is based on observations for 2,335 cows in 232 Norwegian freestall-housed dairy herds ranked according to increasing cleanliness score (x-axis).

Table 4. Estimated β with SE, odds ratios (OR), and 95% CI for significant housing variables in a logistic model with binomial distribution[1] for contamination caused by manure recorded on thighs in 232 Norwegian dairy herds

Variable	Class	Herds,[2] n	Estimate	SE	OR	95% CI[3]	*P*-value
Intercept		232	−2.191	0.841	—	—	<0.01
Sawdust	No	31	1.175	0.248	3.24	1.99–5.27	<0.001
	Yes	201	0	0	1.00	1.00	—
Indoor temperature		232	−0.227	0.049	0.80	0.72–0.88	<0.001
Indoor temperature		232	0.006	0.002	1.01	1.003–1.01	<0.001
Manure consistency		232	0.506	0.123	1.66	1.29–2.13	<0.001
Indoor air humidity (relative humidity)		232	0.028	0.008	1.03	1.01–1.04	<0.001
Upper head rail height	No rail	41	0.148	0.186	1.16	0.81–1.67	0.43
	0.52–0.75	43	0.758	0.220	2.13	1.39–3.28	<0.001
	0.76–0.85	38	0.352	0.204	1.42	0.95–2.12	0.085
	0.86–1.18	110	0	0	1.00	1.00	—
Tameness	1 (tame)	1,014[4]	0	0	1.00	1.00	—
	2	902[4]	0.215	0.082	1.24	1.05–1.46	<0.01
	3 and 4 (avoidant)	364[4]	−0.116	0.326	0.89	0.47–1.69	0.722
Cows per stall		232	1.239	0.500	3.45	1.29–9.20	<0.02
Cluster effect (herd)			1.948	0.118	7.01	5.56–8.84	<0.001
Cluster effect (cow)			0.690	0.089	1.99	1.67–2.38	<0.001

[1]Clean or contaminated (1 vs. 2, 3, or 4).

[2]The statistical unit used in the model is n = 4,670 thighs, and it is based on 2,335 cows registered in 232 dairy herds.

[3]95% CI for OR.

[4]The number in the cell is the number of cows. Tameness observations are missing for 55 cows.

floors. For slatted floors, slot and slat width were 140.0 ± 13.6 mm and 39.5 ± 3.2 mm, respectively. Manure with consistency grade 1 or 2 was found in 68.5% of the herds, whereas water-like manure (grade 4) was found in 1.4%. Relative humidity was 71.3 ± 11.5% and indoor temperature 13.1 ± 4.2°C. In the tameness test, 85.1% of the tested animals were score 1 or 2, indicating tame animals. In 39.7% of the herds, mechanical brushes were found; 32.7% had nonmechanical brushes, and no brushes were available for the cows in the remaining herds.

Effect of the Housing Variables on Thigh Cleanliness

Associations of significant housing variables with thigh cleanliness are in Table 4. Of the variables selected, the number of cows per stall showed the highest association with thigh cleanliness, where more cows per stall meant dirtier thighs [odds ratio (**OR**) = 3.45]. In herds not using sawdust as bedding in the freestalls, there was a higher risk (OR = 3.24) of finding cows with dirty thighs compared with herds that were using sawdust. Upper head rails positioned from 0.52 to 0.75 m (OR = 2.13) or 0.76 to 0.85 m (OR = 1.42) above the freestall base were associated with dirtier thighs compared with head rails positioned >0.85 m. More liquid manure (a high manure consistency score) was associated with dirtier thighs (OR = 1.66) compared with a low manure consistency score. Herds with an indoor temperature >10°C were associated with cleaner thighs (OR = 0.80) compared with lower temperatures. The cleanest cows were found in the temperature zone between 10 and 15°C (calculated in a spreadsheet). When indoor temperature was >15°C, the dirtiness of thighs increased with increasing temperature. Herds with calm and tame cows (grade 1) were associated with cleaner cows than herds graded 2 for tameness (OR = 1.24). A 10-percentage-unit increase in RH resulted in dirtier thighs [OR = 1.32 calculated as ($e^{0.028\times10}$)] compared with lower RH. The cluster effects showed an OR = 7.01 for finding another dirty cow in a herd (score 2 to 4) with dirty cows. Furthermore, the risk of the right thigh being dirty when the left thigh was dirty was OR = 1.99. No random effect of observer was found in the statistical analyses.

DISCUSSION

Cow Cleanliness

In support of previous studies (Schreiner and Ruegg, 2003; Veissier et al., 2004; Breen et al., 2009), the present study showed that the cows were relatively clean on the udder and belly, dirtier on thigh and the rear part of the body, and dirtiest on the legs. Generally, the total cow cleanliness score was surprisingly low, with only 19.7% scoring more than 10 points, and only 2.0% with more than 15 points. The udder was cleaner compared with those in other studies (Schreiner and Ruegg, 2003; Veissier et al., 2004; Reneau et al., 2005). This was because of smaller herd sizes with a better opportunity for improved individual cleaning and general care. The udder of dairy cows is normally clean because it is cleaned daily in connection with milking (Veissier et al., 2004). The cleanliness score for legs supported results of Schreiner and Ruegg (2003) and Veissier et al. (2004), but was lower than those of Reneau et al. (2005) and Breen et al. (2009). The legs are normally the dirtiest part of the animal, because the cows walk in the manure covering the alley. The cleanliness score for the rear part of the body was lower than that reported by Veissier et al. (2004) and Reneau et al. (2005), whereas the thigh cleanliness score supported those reported in the 2 studies.

Thigh Cleanliness

The cluster effect of herd (OR = 7.01) indicates that dirty thighs were strongly associated with herd. Herd properties are more important for thigh cleanliness than individual properties. This is in contrast to Schreiner and Ruegg (2003), Veissier et al. (2004), and Reneau et al. (2005), who indicated the effect of herd to be of minor importance. One reason for this discrepancy might be that the smaller herd sizes in this study offered a better opportunity for individual management of the cows. Several housing and management factors influenced thigh cleanliness; thigh cleanliness will be influenced by properties of the lying area. Dirt in the stalls originates from cows defecating when lying in the stall, from cows standing in or beside the stalls, or it is transported on the feet and legs of the cows into the stalls from the alleys; however, no information about the origins of contamination was recorded in present study. Despite the small number of eliminative behaviors occurring in the stall, Tucker et al. (2005) reported that a large proportion of defecations occur while cows are lying down; hence, a better understanding of this behavior may be useful for improving stall design and to keep cows cleaner. An upper head rail positioned between 0.52 and 0.85 m above the stall base was associated with dirtier thighs. In this context, Veissier et al. (2004) investigated stall design in a field study, and suspected that the head rails had an influence on behavior of cows when standing up, and thereby on cow cleanliness, because they found that an "enclosed" front construction was associated with dirtier cows. This finding indicated that the freestall design should be with fewer rails to allow more space for the cows to lunge forward to attain improved cleanliness. Use of sawdust as bedding was positively associated with thigh cleanliness, whereas the amount of bedding recorded was one of the variables excluded before running the full model. The amount of sawdust used per stall was quite low, 0.6 ± 1.2 L per stall for all herds, but apparently enough to positively influence stall cleanliness.

A high density of cows (a high number of cows per freestall) means more manure per unit of area. One might expect an association with more contaminated animals, which we found, and which supports Veissier et al. (2004). Increased competition for access to the freestalls could force animals to use the alleys for lying. A positive effect of manure viscosity was found, in which drier manure was associated with cleaner thighs, supporting Hughes (2001) and Ward et al. (2002). More liquid manure will splash when cows are moving or defecating in the alleys and it will cover a larger area of the stall surface and the bodies of the animals. A few studies compare the finding that a higher indoor temperature is associated with cleaner thighs and that optimal thigh cleanliness is observed in the temperature range from 10 to 15°C. Some studies on cow cleanliness in relation to temperature do exist (De Palo et al., 2006); however, these studies are more concerned with heat stress. Increased RH was associated with dirtier thighs, suggesting that excreta are stickier under humid conditions, but no studies confirming this were found. Tame cows were associated with cleaner thighs, suggesting that tame cows feel safer or less stressed, making them defecate less or with a denser consistency. Cow cleanliness is often suggested as an indicator of herdsmanship and management (Veissier et al., 2004). In the present study none of the traditional management factors, such as brushing or cleaning out of the stalls, were on the list of significant factors in the full model. One must keep in mind that other measures could be associated with thigh cleanliness because even traits normally being significant (P-values from 0.001 to 0.05) were excluded because of the method used.

CONCLUSIONS

Clean thighs were associated with position of upper head rail, number of cows per stall, use of sawdust, manure consistency, indoor climate, and cow tameness. Freestalls with a construction that hinders normal lying, rising, and standing movements, especially with respect to the position of the upper head rail, should be avoided. Furthermore, focus is needed on indoor climate, and other factors that influence manure consistency, to obtain cows with clean thighs.

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Paper IV

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Flexible and fixed partitions in freestalls—Effects on lying behavior and cow preference

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ABSTRACT

The objective was to investigate the effect of stall partition design on total lying time, lying position, and stall cleanliness, and to evaluate the preferences of cows regarding stalls with traditional fixed stall dividers or flexible stall dividers. Using a crossover design, 16 nonlactating dairy cows were housed singly for 9 d in pens with 2 freestalls, 1 with fixed cantilever dividers and 1 with flexible dividers. The cows were first given access to one stall type, and then to the other type of stall, and finally to both in a preference test. Type of stall divider did not influence lying behavior (13.5 h for fixed versus 14.0 h for flexible, ± 0.4 h), lying positions, or stall cleanliness; however, the cows showed a preference for lying in the flexible stalls (65.2 for flexible vs. 34.8 for fixed ± 8.2%). This indicated that cows are able to distinguish between type of stall divider and that it is important to them; however, it is not clear if the reason for this is the shape or the properties of the dividers. We concluded that cattle chose a flexible stall divider over a fixed one, but the long-term consequences of this preference are not clear, because no obvious changes in stall usage were observed when cows were only given access to one type of divider.
Key words: freestall, stall divider, stall partition, lying time

INTRODUCTION

The basic idea of the freestall was to control defecation behaviors of cows to reduce workload and use of bedding (Bramley, 1962). The function of the structural parts of the freestall is to provide the cows with a comfortable place for rest (stall base) and to restrict lengthwise (head and neck rails and brisket locator) and lateral (stall divider) positions and movements. Stall design is of major importance for achieving hygienic conditions, normal lying time, and use of the stall.

Several studies on freestalls have evaluated stall width and length (Tucker et al., 2004), flooring (Nilsson, 1988; Fulwider and Palmer, 2004; Ruud et al., 2010**[AU1: 2010a or 2010b?]**), neck rail (Tucker et al., 2005; Fregonesi et al., 2009), head rails (Veissier et al., 2004), brisket locator (Tucker et al., 2006), and use of bedding (Wander, 1979; Tucker and Weary, 2004). Thus, the design of the major parts of freestalls is well described. The situation regarding freestall dividers is different, as the development appears to be industry driven. In general, the knowledge on effects of stall divider design on lying behavior, cleanliness, and preference is limited. One exception is O'Connell et al. (1992), who compared an old, enclosed type of divider ("Newton Rigg") with more open cantilever dividers ("Dutch Comfort") and found that the occupancy rate increased with the latter type of divider.

The function of the freestall partitions is to separate cows while lying, define the place for lying, guide the cow when entering or exiting a stall, protect her while resting (Gamroth and Stokes, 1999), and prevent her from turning in the stall (Irish and Merrill, 1986). These functions should be performed without causing injury or entrapment, and space needed for normal lying down and rising behavior should be available (Fregonesi et al., 2009). If the forward lunge movement of the cow is obstructed, it is important that the cow can side lunge when rising; however, it could be argued that this is a less preferred alternative compared with straight forward rising (McFarland and Graves, 1995). In a side lunging situation, the upper part of the divider will act as a neck rail; hence, the general recommendation is that the height of the divider should be approximately as high as the neck rail (Anderson, 2008). The lower part of the divider rail should allow some space for legs and the udder (CIGR, 1994). The pattern in the development of freestalls and stall dividers is toward a more open construction, allowing normal ascent and descent movements (Anderson, 2008). Diagonal standing and lying are associated with reduced stall cleanliness (Ruud et al., 2011); hence, the position of the cow should ideally be parallel to the long axis of the stall. A fixed stall divider design has been used in the belief that it would make the cows lie straighter in the

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stall, whereas stall design variables restricting the lunge space or standing position, such as head and neck rail position, are what initially forces them to lie diagonally in the stalls.

Rails and freestall components that are yielding reduce the contact pressure to the body and lessen the risk for skin damage (Blom et al., 1984). One may speculate that flexible dividers do not provide enough restriction to prevent cows from turning in the stall or performing other nonpreferred behaviors such as lying more diagonally or defecating in the stall. Wandel and Jungbluth (1997) compared a relatively open freestall design with a free-swinging horizontal wooden plank as a divider to a conventional stall ("English stand") and concluded that simple steering was effective and gentle to the animals. Aland et al. (2009) found that vertically positioned elastic partitions used in tiestalls positively influenced stall cleanliness and lying position, but did not affect lying time. Flexible stall dividers in freestalls are new and we know of no study that has investigated their effects on activity, lying position, and hygiene. The objective was to investigate effects of stall partition design on total lying time, lying position, and stall cleanliness, and on cow preferences regarding stalls with fixed or flexible stall dividers.

MATERIALS AND METHODS

Experimental Design

Using a crossover design, 4 replicates of 4 nonlactating dairy cows (n = 16 cows) were housed singly for 9 d in pens with 2 freestalls, 1 with fixed cantilever dividers (hereafter, fixed) and **[AU2: Note: whole words in all caps are distracting and difficult to read; changed throughout to fixed and flexible]** 1 with flexible dividers (hereafter, flexible). A solid gate was used for blocking the stalls not in use during a treatment period. Cows were selected pairwise according to parity and shoulder height and were equally distributed between treatments. In period 1 (4 d), half of the cows had access only to the fixed freestall, while the other half had access only to the flexible freestalls, and the cows were switched to the opposite treatment in period 2 (4 d). In period 3 (1 d), all cows had free access to both freestalls in a preference test. The adjustment period before observing behavior in restriction periods 1 and 2 was 2 d; it could not be longer due to management reasons on the university farm.

Experimental Pens and Freestall Design

Four experimental pens were established in an insulated, mechanically ventilated room with an ambient indoor air temperature of 7.5 ± 2.7°C (mean ± SD). In each pen (6.50 by 3.60 m including the freestalls) were 2 freestalls (Figure 1), one of each type, equally allocated on the left or right side in the pens.

Solid walls were present between each pen in the freestall area to minimize the influence of social ranking on lying behavior. In the activity area, a simple gate consisting of 2 horizontal bars separated the pens. All freestalls measured 1.20 × 2.40 m, with 0.40 m of free space on each side of the stalls. All stalls were equipped with the same M35R mattresses from DeLaval (Tumba, Sweden). To optimize freestall cleanliness, data from a cross-sectional field study in 232 herds on freestall

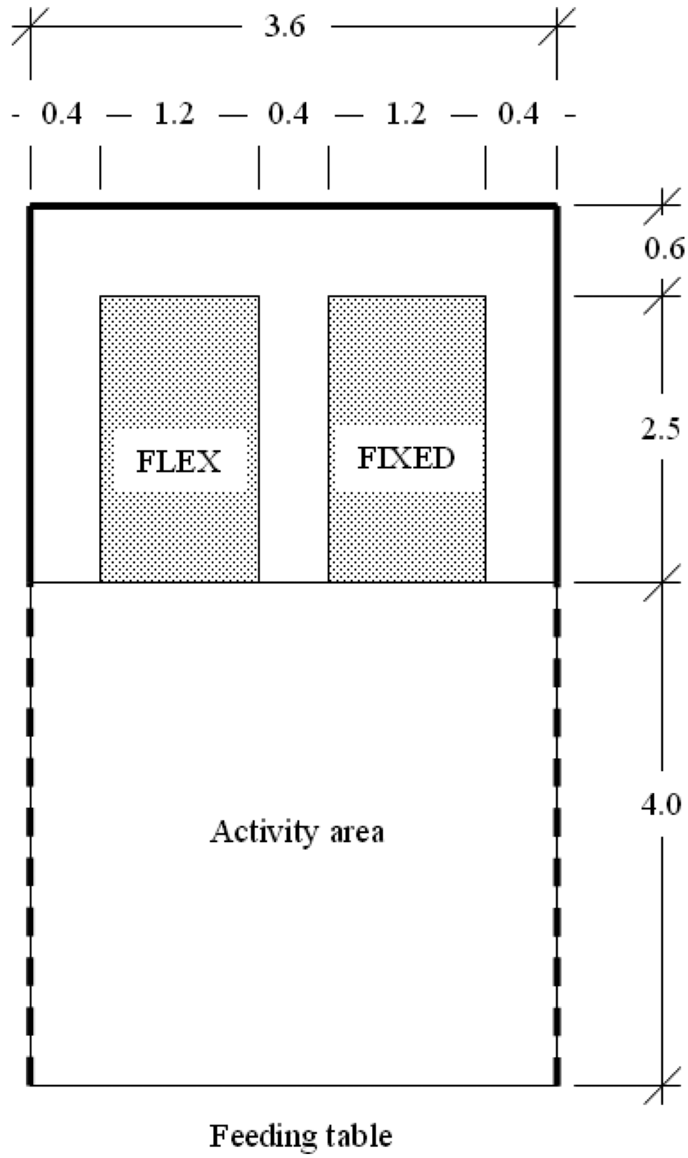

Figure 1. The study cows were singly housed in experimental pens with 1 freestall with flexible stall dividers (FLEX) and 1 stall with looped steel pipeline dividers (FIXED).

design from Ruud et al. (2010b, 2011) were used to determine the position of head and neck rails and the brisket locator. The stall base sloped 2% backward, a brisket locator (0.10 m high) was located 1.82 m from rear curb, and there was no lower head rail. The upper head rail was located 2.35 m from the rear curb (horizontally) and 0.85 m above the floor, and a neck rail (steel pipeline, 50 mm in diameter) was located on a diagonal 2.00 m from the rear curb and 1.09 m above the top of the mattresses. The height of the rear curb was 0.25 m. The fixed divider was a commercial, standard pipeline divider (CC1800; De Laval), whereas the flexible divider was made of a straight glass fiber rod (40 mm in diameter) with an external PVC sleeve (Freedom stall, J&D Manufacturing, Eau Claire, WI; Figure 2). The length of the rod was 2.40 m and it was attached in a bracket on the floor in front of the brisket locator. The height of the rear end of the rod was 1.08 m above the rear curb.

Animals and Management

The 16 nonlactating, healthy dairy cows of the Norwegian Red dairy breed had completed 2.8 ± 1.4 lactations and had 37.7 ± 9.2 d left until expected calving, calculated at d 1 of the experiment. Mean shoulder height was 1.35 ± 0.03 m, which is close to the mean for this breed (Nygaard, 1983; Sveberg et al., 2007). All cows came from the university herd and were previously housed in a freestall housing system with fixed, cantilever steel pipeline stall dividers. The cows were randomly allocated to pen. The animals were fed grass silage for ad libitum consumption twice daily at 0800 and 1630 h, and water was available continuously. The stalls and pens were cleaned immediately after each feeding and only a limited amount of fine sawdust (approximately 0.2 L) was added to ensure the visibility of the grid lines on the mattresses.

Behavioral Observations

A digital video camera was located above each freestall and connected to a computer with a digital surveillance system from MSH Video software (MSH Video, Riga, Latvia). Artificial lights were on 24 h/d. To score the position of the cows when lying in the stall, gridlines with 0.1 m spacing were painted on the floor in the rearmost meter of the stall and extending 0.4 m to either side of the stall. The cows were video-recorded the last 2 d of periods 1 (48 h) and 2 (48 h) and the entire period 3 (24 h). The body positions in the stall as well as the activities were recorded every 10th min (instantaneous sampling) using the following ethogram.

Activity (Periods 1 and 2). Activity was recorded as cows were (1) lying in the stall, (2) standing with 2 feet in the stall, (3) standing with 4 feet in the stall, or (4) standing in the activity area.

Lying Position (Periods 1 and 2). Lying position was observed for cows when using the freestalls and recorded as follows: (1) the lateral position was the greatest distance horizontally from the outermost body part to the lateral stall border; (2) the lengthwise position was the horizontal distance from rear curb to the root of the tail (basis caudae); (3) the angle of the cows relative to the length axis of the stall was (a) cows lying straight in the stall and without any contact between the cow and the stall divider, (b) cows lying straight in the stall and with contact between cow and stall divider, (c) cows lying with either shoulder (scapulae crista) or hip (tuber coxae) in contact with stall divider, or (d) cows lying with shoulder and hips in contact with stall dividers on opposite sides; and (4) the head posture in relation to body was when lying in

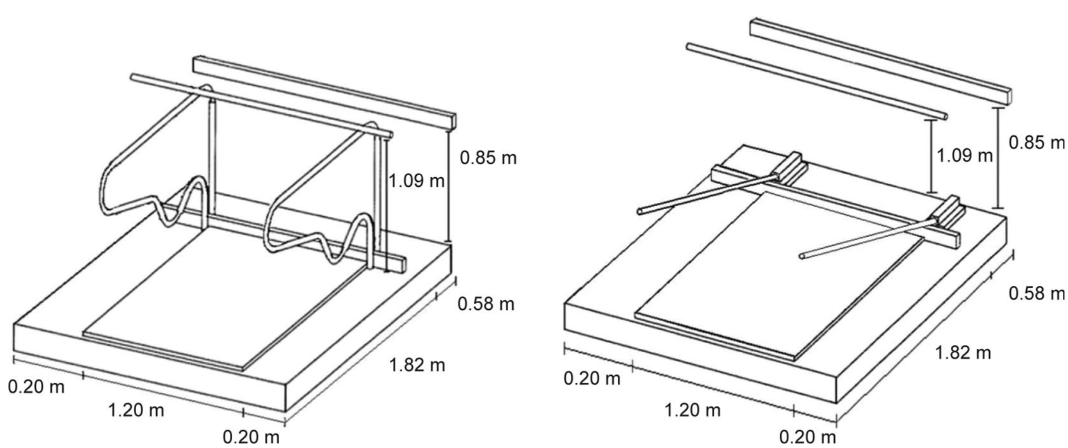

Figure 2. The freestalls used in present study were the De Laval CC 1800 freestall (DeLaval, Tumba, Sweden; left) and the Freedom stall (J&D Manufacturing, Eau Claire, WI; right).

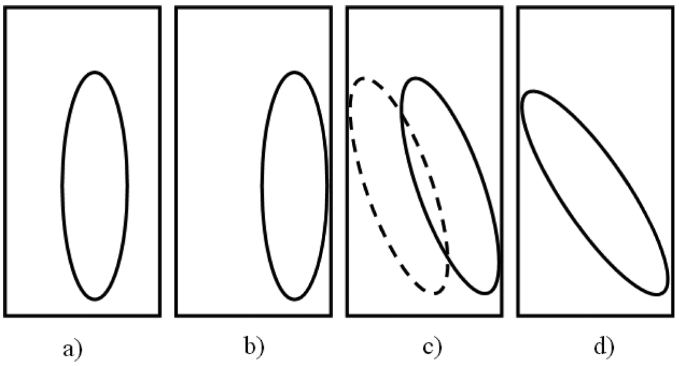

Figure 3. The angle of the cows relative to the length axis of the stall was recorded as (a) cows lying straight in stall without contact between cow and stall divider; (b) cows lying straight in stall with contact between cow and stall divider; (c) cows lying with either shoulder or hip in contact with stall divider; or (d) cows lying with shoulder and hip in contact with stall dividers on opposite sides.

the stall as (a) straight forward, (b) to the side, or (c) backward in contact with the body (Figure 3).

Preference Test (Period 3). In the preference test, the behavior of each cow was scored every 10th minute into one of the following categories: (1) lying in the flexible stall, (2) standing with 2 or 4 feet in the flexible stall, (3) lying in the fixed stall, (4) standing with 2 or 4 feet in the fixed stall, or (5) standing in the activity area. The first stall where a cow laid down for a minimum of 2 subsequent observations after the morning feeding in period 3 was regarded as that cow's preferred first choice. If the time an animal spent in one of the stalls exceeded half of the total time spent in the stalls, that animal was defined as having a preference for that type of stall.

Stall Cleanliness. The rearmost meter of stall base was divided into 8 sectors of 0.50 × 0.40 m, including 0.2 m outside the stall divider. Stall cleanliness was recorded immediately after each feeding as number of cow droppings (>0.05 m in diameter) per stall sector.

Statistical Analysis

For the statistical analyses, cow was the statistical unit. Based on the recorded data from multiple days per cow and treatment, individual means were first calculated and then used in the analyses. Treatment effects on activity, lying position, and preferences were tested by the one-way paired *t*-test procedure in JMP (version 7.0, SAS Institute Inc., Cary, NC), and all tests had 14 df.

RESULTS

One of the cows lay only in the activity area (i.e., never used any of the freestalls for lying) and was excluded from the data set. All results are based on n = 15 cows. None of the other cows was observed lying in the activity area.

Activity (Periods 1 and 2)

The observed lying time was 13.5 to 14.0 ± 0.4 h h/d (mean ± SE). When comparing fixed and flexible stalls, no differences were found in total lying time, time spent standing in stall with 2 or 4 hooves, or in total standing time/24 h ($P > 0.15$; Table 1).

Lying Position

A lying position with some part of the body outside the lateral stall border was adopted by almost all cows in both treatments, because more than 95% of the observations were for cows observed with part of the body outside the stall border. The most prevalent lateral lying position for cows in fixed stalls was from 0.1 to 0.2 m to the side of the stall border. In flexible stalls, a position >0.2 m outside the stall border was prevalent; however, no statistical differences between the treatments were found ($P > 0.15$; Figure 4).

Lengthwise lying position resulted in the cows spending more than 75% of their time lying in a stall with the tail root behind the rear curb of the stall for both treatments. Even though cows were expected to lie more forward in the flexible stalls, no statistical differences were found regarding the lengthwise lying position in the stalls ($P > 0.15$). Regarding the angle of the cow versus stall, cows in both treatments spent 70 to 80% of the time lying straight in the stall without being in contact with the dividers and 4 to 9% of the time lying straight in the stall in contact with the divider. No differences were found regarding angle of the cows versus length axis of stall ($P < 0.15$). A tendency ($P < 0.08$) was observed for cows lying diagonally with contact between divider and hip or shoulder (Figure 5). Lying with hip and shoulder in contact with the stall divider

Table 1. Lying time and time spent standing in stall for fixed or flexible stall dividers (n = 15 cows)

Activity	Fixed	Flexible	SE	*P*-value
Lying time, h/24 h	13.49	13.95	0.36	>0.15
Standing with front hooves in stall, min/24 h	84.7	80.0	16.11	>0.15
Standing with 4 hooves in stall, min/24 h	26.7	20.0	9.71	>0.15
Standing in stall, total time, min/24 h	111.3	100.0	16.35	>0.15

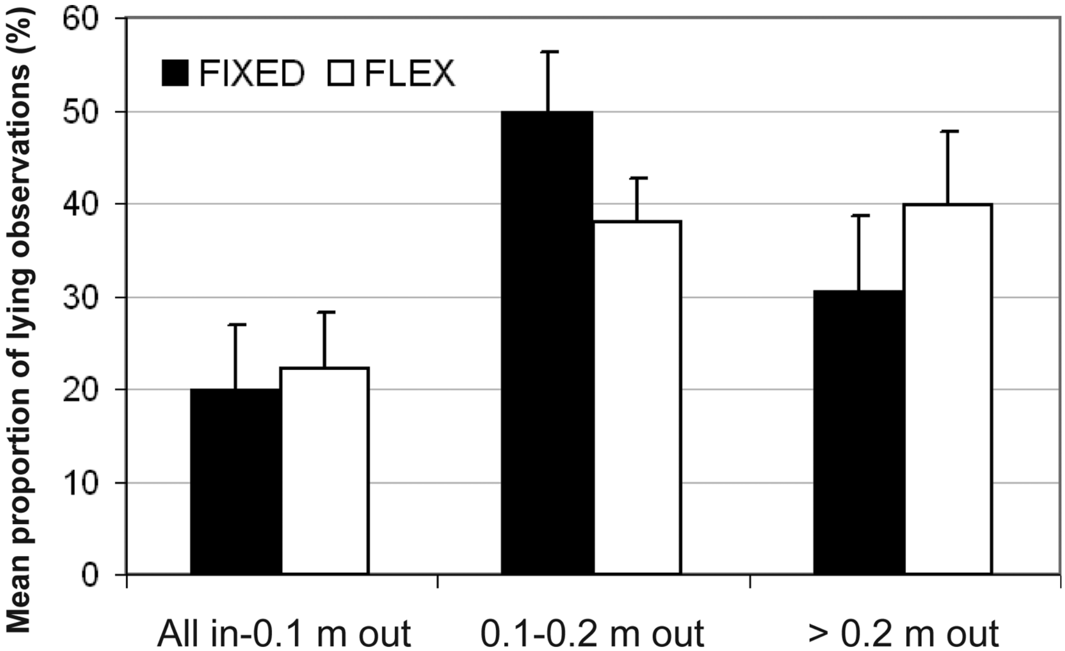

Figure 4. Lateral position of nonlactating dairy cows (n = 15) recorded as the horizontal distance from the most extreme position of a body part to the lateral stall border in freestalls with fixed and flexible dividers, expressed as mean proportion of recorded lying observations (mean ± SE).

at opposite sides was observed occasionally for 3 cows in the flexible treatment.

The cows kept the head straight forward for approximately 30% of the time they were lying, to the side for 60%, and along the body for the remaining 10% of the total lying time. Treatment did not influence the positions of the head ($P > 0.15$).

Preference Test (Period 3)

In the preference test, the cows spent a greater proportion of the time lying in the flexible stalls than in the fixed stalls (65.2% vs. 34.8% ± 8.2%; $P < 0.02$). Large individual differences were observed (Table 2). Ten cows showed a preference for lying in the flexible stall and 5 cows for the fixed stall. Further, 11 of 15 cows (73.3%) had the flexible stalls as their preferred first choice when lying down after the morning feeding in study period 3. Standing in the stall with 2 or 4 feet represented only 9.0% of the observations for time spent in the stall. We found that 93.3% of cows preferring to lie in one particular type of stall also preferred

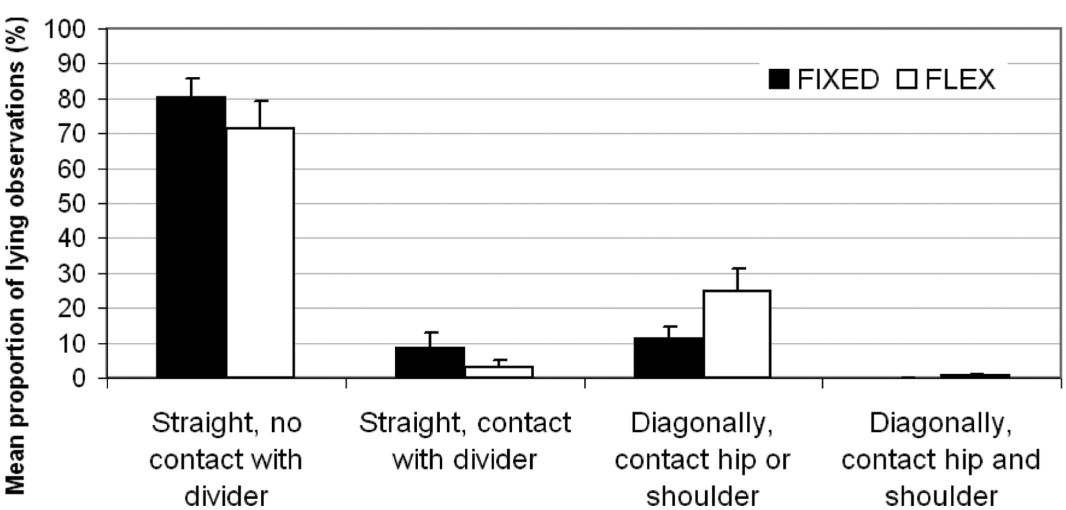

Figure 5. The lying positions of nonlactating dairy cows (n = 15) in freestalls with fixed and flexible dividers recorded as contact with the divider and angle of the cow relative to the length axis of the stall, expressed as mean proportion of recorded lying observations (mean ± SE).

Table 2. Preference for freestalls with fixed or flexible stall dividers tested with single-housed nonlactating dairy cows (n = 15) in pens with free access to both types of stalls for a period of 24 h

Cow no.	Lying, % of total lying time		Standing, % of total standing time	
	Fixed	Flexible	Fixed	Flexible
1	0.0	100*	0.0	100.0*
2	48.8	51.3*	46.2	53.8*
3	6.7	93.3*	8.3	91.7*
4	60.2*	39.8	80.0*	20.0
5	17.3	82.7*	20.0	80.0*
6	78.1*	21.9	66.7*	33.3
7	0.0	100*	0.0	100.0*
8	23.7	76.3*	62.5*	37.5
9	0.0	100*	0.0	100.0*
10	30.1	69.9*	15.0	85.0*
11	100*	0.0	90.9*	9.1
12	65.1*	34.9	71.4*	28.6
13	12.0	88.0*	40.0	60.0*
14	58.2*	41.8	75.0*	25.0
15	21.4	78.6*	28.6	71.4*
Mean	34.8	65.2[1]	40.3	59.7[2]

[1]Preference for lying in flexible stalls (SEM = 8.2%; $P < 0.02$).

[2]Tendency for preferring to stand in flexible stalls (SEM = 8.3%; $P = 0.11$).

*Preferred stall for lying or standing.

to stand in the same type of stall (pairwise correlation coefficient = 0.90; $P < 0.001$; Table 2).

Stall Cleanliness

All freestalls stayed clean during the experimental period; only 2 droppings were observed in all the stalls during the study, 1 in flexible and 1 in the fixed stalls. Hence, no analysis on these data was performed.

DISCUSSION

In present study, no differences in activity, lying positions, or cleanliness were found. Despite that, the majority of the cows preferred the flexible stalls. Investigations on flexible dividers are few; however, the preferences from present study support Gwynn et al. (1991), who found that cows prefer a rope instead of a fixed timber structure as the lower rail of the divider. Further, Wandel and Jungbluth (1997) found that cows prefer a free-swinging wooden plank divider compared with a conventional fixed divider.

As described by Tucker et al. (2003), interpreting the results of preference studies requires attention to several factors such as social factors and previous experiences of the cows. All the cows in present study were housed individually to reduce social influences on their preferences. They went through a restriction period with both types of stalls before the preference test. Results from a preference test will be relative (Tucker et al., 2003) and in the present study, the comparison was made with another modern and open stall design. The yield properties of the dividers are probably of minor importance to lying position, because the physical contact with the dividers in the current study was infrequent (L. E. Ruud, unpublished data). In contrast, Blom et al. (1984) found that cows touched the partitions in a freestall 100 to 150 times per day.

The lying times observed in present study supported the lying time for cows in comfortable freestalls in other studies (Tucker and Weary, 2004). In addition, lying time was similar between treatments, probably because lying time is affected more by the stall base (Wander, 1979; Nilsson, 1988; Manninen et al., 2002) and less so by the stall dimensions (Tucker et al., 2004).

Compared with the results of Tucker et al. (2005), the proportion of time standing with 2 hooves in the stall compared with total stall standing time was relatively high. This may indicate that the neck rail position used in present study was rather restrictive. However, no differences between treatments were found in time standing with front hooves or all 4 hooves, or in total stall standing time. The results regarding lying positions as well as head posture indicated that both dividers performed equally well in positioning the cows. Knowledge on the positions of cows when lying in freestalls is meager; hence, no direct comparison was found in the literature for the findings from present study. Veissier et al. (2004) and Tucker et al. (2004, 2005) have reported on stall design without considering lying position.

When using a less restrictive stall construction, one may expect an increased risk for flexible stalls to be contaminated compared with fixed stalls. However, stall type had no negative effect on stall cleanliness in the current study. The very clean stalls in both types of treatment were probably due to the optimized stall and stall front design based on the studies of Ruud et al. (2010a,b, 2011). Even though we report promising results with flexible dividers in the current study, effects of social housing (e.g., cows lying next to each other) or implications of a head-to-head presentation in a normal group-housing situation should be followed up in a future study.

CONCLUSIONS

The preferences of the cows indicate that they were able to distinguish between types of stall dividers, and that stall divider type is important for them, even though it was not clear if the reason for their choice was the shape or the yielding properties of the dividers. Type of stall divider had no effect on lying behavior. After conducting the present study, we conclude that flexible dividers were more preferred by the cows than fixed ones, with respect to cow behavior.

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