Dairy freestall barn layouts and space allocation
Effect on milk yield, building costs and labour input in small herds

Planløsninger og arealbruk i løsdriftsfjøs for melkekyr
Effekt på melkeytelse, byggekostnader og arbeidstidsforbruk i små besetninger

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Department of Mathematical Sciences and Technology
Philosophiae Doctor (PhD) Thesis 2010:32

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It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow.

Robert H. Goddard

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Drawing on page 1: Gunnhild and Sigrid Næss

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Philosophiae Doctor Thesis 2010: 32, Universitetet for miljø- og biovitenskap.

Tradisjonelt har melkekyr i små besetninger blitt oppstallet i båsfjøs. Selv om bygningskostnadene er lavere for båsfjøs, er løsdriftsfjøs (liggebåsfjøs) generelt mindre arbeidskrevende og dyrehelsa er totalt sett bedre. Melkeytelsen ser ut til å ligge på omtrent samme nivå i båsfjøs og løsdriftsfjøs. Likevel er det påvist at melkeytelsen i små løsdriftsfjøs er signifikant lavere enn i båsfjøs. Dette indikerer at det er noen forhold som kan forbedres i små løsdriftsfjøs. Utfordringen er å utforme egnede planløsninger innenfor kostnadsrammene på små bruk. Overordnet mål for denne avhandlingen var å undersøke effekten av ulike planløsninger og arealdisponering på melkeytelse, byggekostnader og behov for arbeidskraft i små løsdriftsfjøs for melkekyr. Resultatene viser en markant variasjon i hvor mye areal som ble satt av til melkekyrne, og dette har betydelig innvirkning på byggekostnadene. De totale byggekostnadene (kr/m^2) gikk raskt nedover inntil en grunnflate på omtrent 1000 m^2. Arbeidsbehovet (timer/ku) ble redusert med stigende besetningsstørrelse, og var høyere i ombygde fjøs enn i nye fjøs. Imidlertid klarte bønder som valgte å bygge om eksisterende fjøs å realisere en modernisert bygning for en gitt besetningsstørrelse til en lavere pris enn ved nybygging. Det er begrenset forskning som er gjort på effekten på melkekyr ved ulik arealbruk. Denne studien viser at melkekyr i løsdriftsfjøs påvirkes av flere forhold ved bygningen. Liten kapasitet på drikkekar, manglende syke- og fødebinger og planløsninger med blindganger var alle forhold som resulterte i redusert melkeytelse. Kyr i første laktasjon så ut til å være mer følsomme for redusert plass. Derimot hadde ikke besetningsstørrelsen i seg selv noen innvirkning på melkeytelsen. Observerte effekter av automatisk melking (AMS) var redusert arealbehov for melking, redusert arbeidsbehov, økt melkeytelse og økt mekaniseringskostnad. Enten en ny bygning skal settes opp eller en bygning skal bygges om, må plass til dyra, byggekostnadene, arbeidsbehovet og dyrevelferden tas med i betraktningen. Å spare plass ved å tillate blindganger, utelate syke- og fødebinger eller å ha knapp tilgang på drikkekar er absolutt ikke å anbefale.

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Abstract

Næss, G. 2010: Dairy freestall barn layouts and space allocation - Effect on milk yield, building costs and labour input in small herds.
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Dairy cattle in small herds have traditionally been housed in tie-stall barns. Even though the building costs are lower for small tie-stall barns, freestall barns are in general more labour efficient and are associated with improved cow health. Milk yield in freestall barns seems in general to be at the same level as in tie-stall barns. However, on the smallest farms milk yield has been shown to be significantly lower than for tie-stall barns. This indicates that there are conditions in small dairy barns that could be improved. The challenge is to design proper freestall barn layouts for small dairy herds without exceeding the budgets on these farms. The overall aim of this thesis was to investigate the effects of different layouts and space allocation of freestall dairy barns on milk yield, building costs and labour input in small herds. The results show that space allocated for dairy cows in freestall barns varies considerably and this variation has a significant effect on initial building costs. The total building costs per m^2 decreased rapidly up to approximately 1000 m^2. Required labour input per cow decreased by increasing herd size, and was higher for remodelled than for new barns. Farmers who remodelled their barns were able to attain a modernized building of a certain size for a lower cost, compared to a completely new building. Previous information about the effects of space allocation on dairy cows is scarce. The present results show that dairy cows kept in freestall barns are affected by a number of housing conditions. Low water trough capacity, lack of facilities for special needs cows and layouts with dead end alleys all resulted in decreased milk yield. Primiparous cows seem to be more sensitive about reduced space allocated and access to resources. Herd size, however, was not the reason for reduced milk yield. Decreased space allocation and required labour input, increased mechanization costs and milk yield are all effects of installing automatic milking. Building new or remodelling facilities, space allocation, building costs, required labour input and animal welfare must be considered. Saving space by allowing dead end alleys, skipping the separation area or reducing water trough capacity is absolutely not recommendable.

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List of papers

Paper I
Næss, G. and Bøe, K. (2010).
Layouts and space allocation in Norwegian freestall dairy barns.
Transactions of the ASABE, 53(2), 605-611.

Paper II
Næss, G., Bøe, K. and Østerås, O. (2010).
Layouts for small freestall dairy barns: effect on milk yield for cows in different parities.
Submitted

Paper III
Næss, G. and Stokstad, G. (2010).
Dairy barn layout and construction: Effects on initial building costs
Submitted

Paper IV
Næss, G. and Bøe, K. (2010).
Labour input in small cubicle dairy barns with different layouts and mechanization levels.
Submitted

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Introduction

General introduction

The most common loose housing system for dairy cows is the freestall (cubicle) barn (Bickert et al., 2000). The system was first developed in the UK in 1957 and the stalls included a kind of mattresses (Bramley, 1962). The idea was to replace straw- and sawdust-bedded tie-stalls or straw yards. In the USA it started in 1960 and already in 1964 it was quite common in some regions. The farmers were satisfied and reported reduction in bedding material and lower labour requirements as the primary benefits (Albright, 1964). The freestall concept is still dominating, though compost bedded pack dairy barn also might be an alternative loose housing system (Barberg et al., 2007).

Dairy cattle in small herds have traditionally been housed in tie-stall barns, whereas farmers with more than 80-100 cows generally have adopted freestall housing (Graves, 1989). This pattern seems to be based primarily on financial grounds. Even though the building costs are lower for small tie-stall barns (Reichel, 2005), freestall barns are more labour efficient (Boyd, 1969; Stahl et al., 1999) and are associated with improved cow health (Ekesbo, 1966; Bakken et al., 1988). Milk yield in freestall barns seems to be at the same level as in tie-stall barns (Konggaard, 1977) or slightly lower in herds < 27 cows (Simensen et al., 2010).

In cold regions cattle housing is necessary for animal welfare as well as working conditions (Figure 1). However, uninsulated or open barns are shown to be sufficient to avoid high-yielding dairy cows from overtaxing the thermoregulatory ability in cold climate and the milk yield is reported to be at the same level as in insulated barns (Heizer et al., 1953; Arave et al., 1994; Zähner et al., 2004).

Increased focus on animal welfare also challenges the present practise for keeping cattle in captivity. In many European countries governments have responded to the public concerns about animal welfare by adopting legislations that prohibit certain practices (Rushen et al., 2008). In Norway, the government has decided that all tie-stall barns should be replaced by loose housing before year 2024 (Landbruksdepartementet, 2004).

Figure 1: In cold regions housing for dairy cows is necessary

In modern animal husbandry cattle are kept in much higher densities compared to their life in natural environments. In order to increase animal welfare, cattle behaviour in natural environments must be considered. Cattle are gregarious animals, and will show clear signs of stress when separated from other animals (Rushen et al., 1999). As summed up by Tucker (2009) the structure within groups of cattle is categorized by both aggressive and affiliative behaviour and the hierarchy is established and maintained by both kinds of social interaction. Over time the aggressive interactions in general will decline as the animals become more familiar to each other. However this dominant – subordinate relationship may influence access to resources such as food and lying space.

Among feral cattle there are long-lasting associations between individual animals, yet in intensive cattle systems with increased stocking densities the animals will not have the same opportunity to choose which individuals they want to stay close to (Rushen et al., 2008). Subordinate cows might be losers in such systems as stated by Thomsen et al., (2007). Primiparous cows are found to benefit from separate grouping from older animals by increased feed intake and productivity (Krohn and Konggaard, 1979; Grant and Albright, 2001). Kjæstad and Myren (2001a; b) found that approximately one third of the heifers refused to use the freestalls for the first two weeks after being transferred to the lactating cow group. However, separating primiparous cows is not easy feasible in small herds.

Layout and space allocation

The freestall system for dairy cows, where space is allocated for different specific functions, adapt for tailor-made areas for resting, walking, feeding, drinking, milking and separation (Figure 2). There are many guidelines and criteria for space allocation and the design of these specific areas. However, these guidelines differ quite much between countries (CIGR, 1994; Bickert et al., 2000; Graves, 2000; Landbruksdepartementet, 2004; DLBR, 2005).

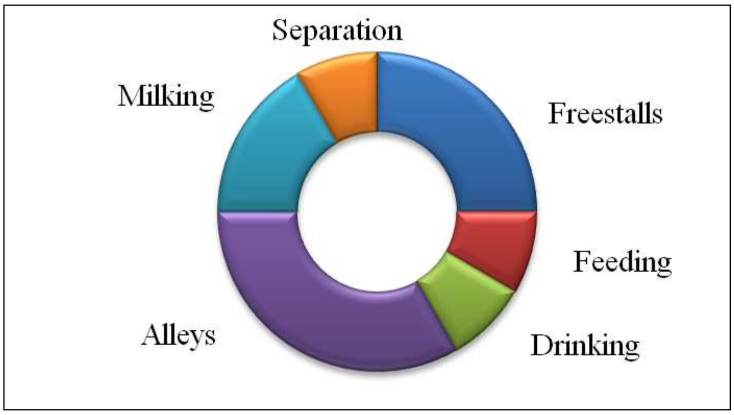

Figure 2: Specific areas for lactating dairy cows in a freestall barn

Compact floor plans including covered systems with indoor feeding (Graves, 1989) are more common in colder regions due to higher construction costs for insulation and snow load. According to Graves (1989) there was a trend in the USA in the 1970s towards minimizing housing space per animal in an attempt to reduce building costs, and this trend seemed to continue in Norway in the 1980s.

Information about the effect of a general decrease in space allowance on dairy milk yield is scarce. Fregonesi and Leaver (2002) did not find any effect of reduced total space on feed intake or milk production in freestall systems, but field observations indicate that allowing more space is common in high producing herds (Graves, 1989). However, studies have shown that daily weight gain and feed intake by dairy heifers decreased with decreasing resting area (Fisher et al., 1997; Mogensen et al., 1997) Limited space for bulls is shown to result in lower weight gain (Ingvartsen and Andersen, 1993). Also data from growing-finishing pigs (NCR-89 Committee on Confinement Management of Swine, 1986; Brumm and Miller, 1996) and poultry (Dozier et al., 2006) show that relevant production parameters are impaired by reduced space allowance. Even reduced space for dairy sheep caused a reduction in milk yield (Caroprese et al., 2009). Yet, in all these systems the space is rather uniform and differs from the dairy freestall system. However, many studies have focused on the different modules or “resources” in dairy housing (freestalls, alleys, feed bunk, water supply, milking facilities, and special needs pens) in the freestall barn. When reducing space allocation for these specific areas to a very low level, studies show negative effects on both productivity and behaviour.

Recommendations for dimensions of freestalls differ (CIGR, 1994; Bickert et al., 2000; ASABE, 2006), though freestall dimensions seem to have limited effect on behaviour and lying time (Tucker et al., 2004). The design of the freestall itself should be founded on the body dimensions of the cow (Anderson, 2008), and the size of it should be based on the average size of the 20% largest animals in the herd (CIGR, 1994). The number of freestall rows along a feedline will influence the total area and the available feed bunk space per cow (Graves, 2000). Housing designs with three rows of freestalls cut building space per freestall and may therefore reduce building costs. However, feed bunk space per cow is reduced compared to a two row layout and was shown to result in more competition in front of the feed bunk (Mentink and Cook, 2006).

Overstocking, in terms of more than one cow per freestall, is a result of management routines and not layout, and will certainly influence the space allocated per cow. The behavioural effects of overstocking are characterized by increased competition for freestalls, reduced lying time, shorter resting periods, increased time standing outside the freestalls and poorer locomotion score (e.g. Friend et al., 1977; Bowell et al., 2003; Fregonesi et al., 2007; Krawczel et al., 2008).

Organization of alleys is important for achieving optimal cow traffic and dead end alleys should be avoided (Smith et al., 2000). The walking area consists of alleys and crossovers. The size of this area depends on the width of the alleys and the layout of the barn. There are not many clear recommendations according to the exact space needed for cows in the walking area. Zeeb et al. (1988) said that cows need a walking space of at least 3.5 m^2 / 600 kg bodyweight. This is based on measurements of the body including a social distance of 0.2 m. Danish recommendations claim that the walking area should be no less than 4 m^2 / cow in order to reduce aggressions among cows (DLBR, 2005). Recommendations for alley widths also differ (CIGR, 1994; Bickert et al., 2000; Graves et al., 2006). In general the guidelines demands increased width of alleys by increased herd sizes.

Despite the importance of the effect of alley area allowance, only one study seems to deal with this question. A controlled study carried out by Henneberg et al., (1986) found that reducing the alley width to 1.6 m resulted in abnormal behaviour, and a reduction to 1.2 m gave significantly lower milk yield. The width of alleys and crossovers should at least fit the space cows need to pass each other without getting in touch (Konggaard, 1982), but practical recommendations are much higher (Graves, 2000; Smith et al., 2000).

High yielding dairy cows require much water and there is a significant correlation between water intake and milk yield (Andersson, 1987). In several recommendations (CIGR, 1994; McFarland, 2000), the importance of an adequate water supply is pointed out (Figure 3). However, documentation of possible negative effects on milk yield from reducing the amount of water supply is scarce. Cows are found to prefer, and to drink more, from larger troughs (Pinheiro Machado Filho et al., 2004; Teixeira et al., 2006). Projecting the width of crossovers the space needed for prospective water troughs must be considered (McFarland, 2000).

Figure 3: Water supply is essential for dairy cows.

Gaining access to feed has high priority for cows (Val-Laillet et al., 2008) and overstocking in front of the feed bunk has been shown to negatively influence the cows social interactions (Friend et al., 1977; DeVries et al., 2004), especially for low ranked cows (Huzzey et al., 2006). Increased space is shown to reduce the number of displacements at the feed bunk, especially for cows with lower social status. Wierenga et al. (1985) found that extra space compared to “normal” (< one freestall and one eating place per cow) gave the cows more freedom to determine the moments for resting and eating and they synchronized their activities more. With feed stalls in front of the feed bunk (i.e. partitions between adjacent cows) this effect was more pronounced, yet feed stalls demand additional space (DeVries and von Keyserlingk, 2006). Though it is well documented that the level of confrontations increase by decreased feed bunk space, the daily feed intake do not seem to be disturbed until the feed bunk space is reduced to a very low level (Friend et al., 1977).

Freestall barn layouts seem to have changed little over the 1980s and 1990s. The introduction of robotic milking or ”automatic milking system” (AMS) has had a large impact on layouts and the reduction of space for milking during the 2000s (Rodenburg, 2004).

In front of the milking parlour, space allocated for cows waiting in line for milking is necessary. For manual milking parlours 1.5 – 2.0 m^2 is needed (DLBR, 2005). Automatic milking systems are more area efficient than milking parlours, but need some space dedicated for waiting cows in front of the milking unit (Thune, 2002; Rodenburg, 2004).

There are different groups of “special needs cows” that demand specific attention and extra space (Graves et al., 2006) and the importance of separate areas for these cows is emphasized in all recommendations (e.g. Cook and Nordlund, 2004; Kammel and Graves, 2007). A separation area should be designed for each particular purpose but in small herds some of the cow groups might be consolidated (Kammel and Graves, 2007). The area for transition cows should be dimensioned for the real distribution in calving time that often diverges quite much from a perfect uniformity (Stone, 2000). Often pens for special needs cows are not present, or not in practical use (Vasseur et al., 2010). However, it is most likely that the absence of such areas, in addition to worsen the animal welfare, will influence milk production, but no relevant data seem to exist.

Building costs

On small dairy farms, especially in cold climate regions, high investment costs and lack of investment capital may delay the modernizing of facilities (O'Donoghue et al., 1998; Lazarus et al., 2003). Dairy barns need to be renewed in order to offer proper facilities for improved working conditions and animal welfare.

Annual dairy building costs seem to be more or less constant over time and constitute about 10-15 % of the total costs (Albright, 1964; Gazzarin and Hilty, 2002). Many studies have focused on initial building costs in dairy housing (Achilles et al., 1974; Gartung et al., 1983; Pereira et al., 2003; Fernández et al., 2008) and economies of scale (lower investment costs per cow in larger buildings) has been stated (Hoglund and Albright, 1970; Gjerde, 1996; Gazzarin and Hilty, 2002).

Berg (1995) found that the potential for reducing building costs by building uninsulated dairy barns was low. However, more open buildings (Simon et al., 2007) and also simpler interior (Dolby and Ekelund, 1994) may reduce the building costs considerably.
Barns including posts might be cheaper than completely open rooms (Simon et al., 2007), and make stepwise building possible (Bjerg and Fog, 1985). Domestic regulations, material costs, labour prices and building tradition might also influence the building costs (Van Caenegem, 2003).

An alternative to building new separate buildings is to remodel and expand present buildings. In Scandinavia a gradual expansion of the herd size by remodelling existing buildings to freestalls and parlour systems has been common in order to keep building costs low (Ekelund and Dolby, 1993). Though remodelled facilities may require lower investments, they may also have poorer functionality compared to new buildings (Ekelund and Dolby, 1993; Bewley et al., 2001a). Remodelling or a more gradual expansion may also offer attractive returns compared to more capital-intensive investments in new facilities (Lazarus et al., 2003).

An extensive use of own work in the building process might reduce the cash expenditure (Van Caenegem et al., 2004), but may also negatively affect the milk production during the building period (Aschan and Stockzelius, 1997).

Labour and mechanization

A proper barn layout may reduce the required labour input as stated by Albright (1964). For example a well designed section for special needs cows will simplify the work with maternity cows and cows with health problems (Kammel and Graves, 2007). Increased mechanization level is also expected to reduce the required labour input and probably increase the profit levels, yet often to a higher cost (Hoglund and Albright, 1970; Karszes, 2000).

The dairy work can be divided into milking, feeding, cleaning and other work / management (Hedlund, 2008). The total required labour input per cow varies considerably and seems to constitute about 30-50 hours per cow and year for a 80-100 cow herd, and decreases by increasing herd size (Auernhammer, 1990; Hedlund, 2008). The required labour per cow has gradually been reduced during the last 50 years (Hedlund, 2008), illustrated by Nygaard (1977) who in the 1960s found the labour input to be 63 hours per cow-unit and year in small tie-stall barns.

On family farms most of the work is done by the family themselves. Even though farmers seem to have a strong preference to staying in dairy production, it is obvious that a minimum income is necessary to keep them in business (Lips and Gazzarin, 2008). It might be difficult to renew the facilities and simulations of efficiency on dairy farms based on “best practice” have shown that many small farms had high production costs due to inefficient facilities or working routines (Tauer, 2001). Newer buildings tend to be more efficient (Stahl et al., 1999). Larger farms are early adopters of technology and benefit more from labour-saving technologies (O’Brien et al., 2007). Bewley et al. (2001b) reported that farmers who built all new facilities observed higher production and greater labour efficiency compared to farmers who modified their facilities.

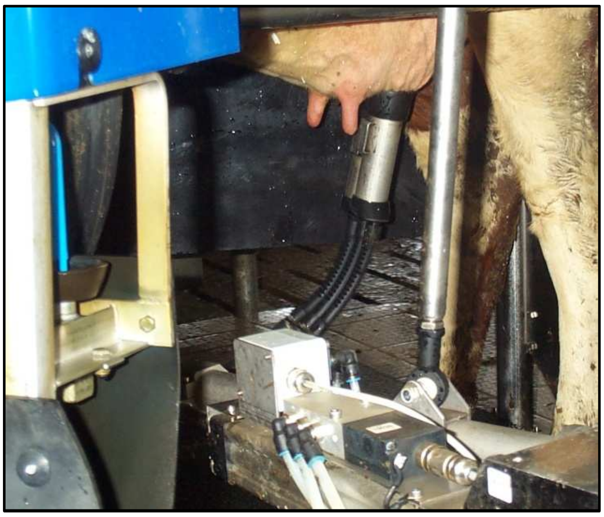

Figure 4: Automatic milking influence working conditions

Traditional milking is the most labour intensive part of the work and constitutes about 50 – 70 % of the work in cubicle housing (Hoglund, 1973; Auernhammer, 1990; Hedlund, 2008). Increased mechanization of milking is about reducing required labour input and thereby reducing the costs (e.g. Wagner et al., 2001; Hyde and Engel, 2002). With AMS the required labour input is expected to be significantly lower (Schön, 2000; Hedlund, 2008), yet investing in AMS is a large investment (Figure 4).

Automatic feeding systems and manure scrapers are other technical innovations that are expected to reduce the required labour input. This is illustrated by a reduction in required labour input for feeding from 30% in the 1960's (Nygaard, 1977) to 13 % in the 2000's (Hedlund, 2008). Pereira et al. (2005) found the costs of slatted floors to be up to 40% higher than floors built for tractor scrapers, and Gartung and Krentler (1987) found the lowest costs manure handling and storage system to be 50% of the most expensive alternative.

However, mechanization and handling systems affect working conditions and animal welfare in addition to building costs and required labour. The mechanization of milking, for example, is not only a question of minimizing costs. The introduction of the AMS during the last decade also has socio-economic effects (Wauters and Mathijs, 2004) by e.g. giving more flexibility with respect to working hours and also effects on the cows by changed daily time budgets (Svennersten-Sjaunja and Pettersson, 2008).

Optimization of layouts

Optimization may be understood as "economically optimization". However, working conditions and animal welfare cannot always be measured in economical terms. On the other hand, good animal welfare might result in increased production, and allocating more space for cows may also make it easier to achieve a good layout. Thus, animal welfare also should be considered when optimizing a barn layout.

As mentioned above there are economies of scale in construction costs of barns. However, increasing the size is not the only way of optimizing building costs. Optimization of layouts can be done by e.g. decreasing building costs, reducing labour input or increasing milk yield (Figure 5). Building costs may be reduced by decreased area or by simplifying the construction. More simple constructions must be expected to last for a shorter period, yet this is not necessarily negative. Traditionally most of the barns are solidly built in Norway. Albright (1964) called these buildings “dairy castles”. After some years the layout and building conditions might be unsuitable for modern husbandry, yet the technical value of the building is still high. In Norway these buildings are often remodelled in order to take care of the “rest value”.

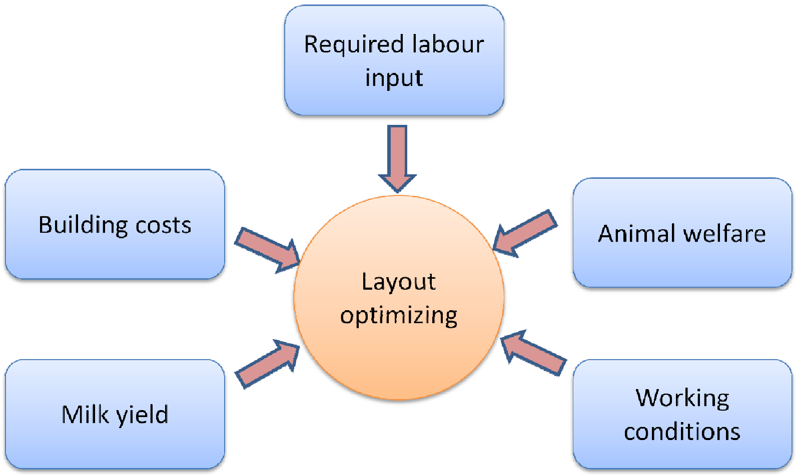

Figure 5: Many conditions must be considered in order to optimize barn layouts.

Simensen et al. (2010) found that milk yield increased with increasing herd sizes in small Norwegian freestall dairy barns. Therefore it is of special interest to examine the space allocation and the layouts in small herds. Approximately 25% of the Norwegian cows are housed in loose housing systems, and mean herd size in freestall barns is 25.8 cows (Simensen et al., 2007). Many other countries also have many small herds.

There are different approaches to studying the optimization of the layout. Some researchers have used algorithms and neural network methods to simulate an optimized layout (Halachmi et al., 2002; Fernandez et al., 2006; Marco, 2008), whereas others have studied the on-farm effects of theoretical benefits choosing particular building layouts and configurations (Bewley et al., 2001a). In order to optimize the space, rather than minimizing it, there is still a need for increased knowledge about this topic.

Aim of the thesis

The overall aim of the thesis was to investigate the effects of different layouts and space allocation of freestall dairy barns on milk yield, building costs and labour input in small herds.

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

- How is the variation in layout and space allocation within recently built freestall dairy barns?
- Is remodelling of dairy barns a recommended way of renewing the facilities?
- How does dairy barn layout and space allocation affect the milk yield for cows in different parities?
- To what extent is there an economy of scale in constructing dairy freestall barns?
- Which conditions affect initial building costs per unit?
- How is the required labour input per unit affected by layout, space allocation, and mechanization?

Summary of material and methods

Selecting study farms

The studies included in this thesis are parts of a larger descriptive and cross-sectional project on freestall housing called “Freestall barns for dairy cattle”. From a questionnaire sent to all dairy advisors in Norway, a list of 2,400 presumably known freestall-housed herds in Norway was obtained. These farmers received a questionnaire covering several aspects of their freestall housing system. To be included in the final study, farmers had to fulfil our inclusion criteria; volunteer to participate, have a herd size > 20 standardized cow years based on the year 2005 (cow year = number of days from first calving to culling within one year, divided by 365), and have a barn built in the years 1995 to 2005. As we expect some housing systems to be common in the future, all barns with AMS (n = 44), with solid concrete floors (n = 105) or rubber solid floors (n = 24) in the alleys were included in the study barns. Traditionally freestall barns in Norway have been constructed with slatted floors and such buildings were only included if they were located in the same municipality as farms mentioned above. The final database included 232 free-stalled dairy herds located all over Norway (Figure 6). Due to missing information about floor plans the final material in this study included 207 herds.

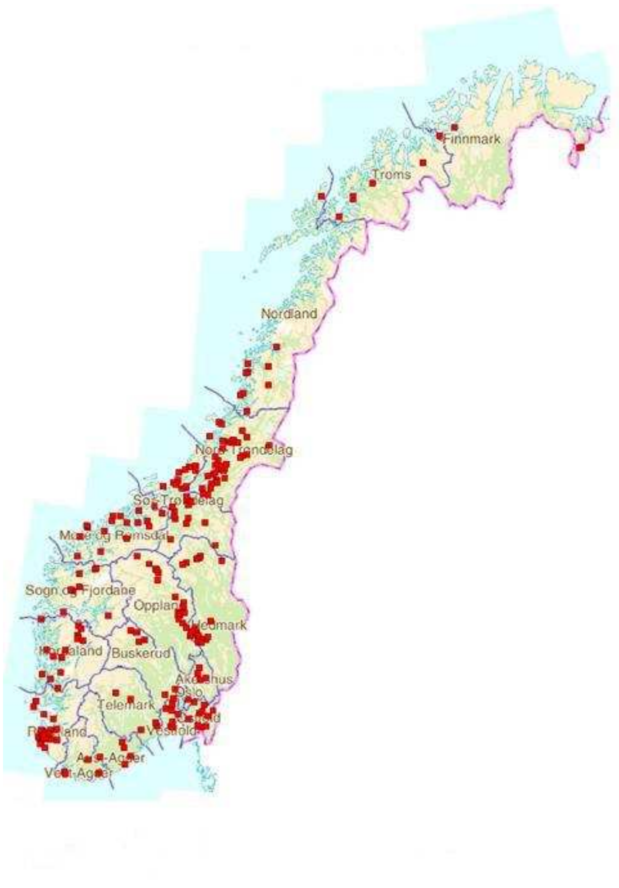

Figure 6: An overview of farms visited during the field work (I. S. Holand, HiNT)

Layout and space allocation data

Layouts from these 207 Norwegian freestall barns, 94 new and 113 rebuilt, with a mean number of freestalls for lactating cows from 42.0 ± 16.5 were obtained and the areas dedicated for milking cows were analyzed. The number of barns included in the separate studies presented in Paper II and Paper IV were reduced to 204 and 201 respectively due to conditions described in the papers. In Paper III 44 layouts were merged with building cost data.

During the period from September 2006 until May 2007 all the barns were visited once by trained observers. Farmers were asked to provide detailed drawings used during the barn-building process. Approximately 80% of the farmers were able to provide such drawings. On these farms all the main dimensions of the building were measured using the electronic measuring device Leica Disto™ type A3 in order to assure that the drawings were correct. For the rest of the buildings, dimensions for indoor length, width and height of the building, alleys, freestalls, pens etc., were measured using the same electronic measuring device. In addition photographs of the barns were taken systematically, both inside and outside, using a digital camera. On the basis of the drawings, measurements and pictures, an accurate floor plan was created using the computer-aided design software VectorWorks™ Architect for each barn. The "total cow area" (TCA) in the barn was defined as the area allocated for lactating cows excluding the feed table (Figure 7), and this area was divided into "free accessible area" (FAA) and "restricted area" (REA).

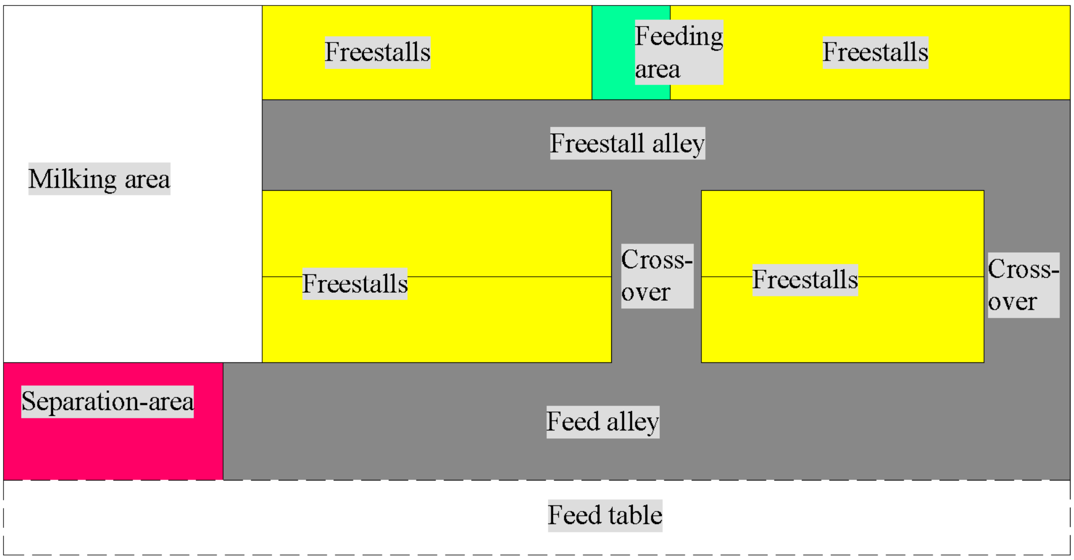

Figure 7: An example of a floor plan.

VectorWorks™ software includes a function that allows automatic calculation of the size (in m^2) of the different areas (freestalls, feeding area, alleys, milking area and separation area). Area data were exported to a spreadsheet for comprehensive analyzes.

In order to avoid an effect of management, especially stocking density (number of cows per freestall), the unit of measure presented in the analyses in Paper I was m^2 per freestall. Hence, we assumed that there was one cow per freestall. In addition to analyzing space allocated in different modules the layouts were analyzed according to how the modules were arranged. Examples are number of freestall rows, location of freestalls and water troughs etc.

Herd and farm data

The cow identity, 305 days milk yield and calving interval data was extracted from the Norwegian Milk Recording System (NDHRS) for the different individual cows, as well as calving and culling date (Osteras et al., 2007). In Paper II the 305 days milk yield dataset contained 20,221 different lactations from 12,118 different cows and 204 different herds. In Paper III building cost data was obtained from farmers and merged with construction, mechanization and layout data from the same barns. Required daily labour input during the winter season was estimated by the farmers in Paper IV. Additionally information about farmers' attitude towards animals (Kielland et al., 2010) and cleanliness of cows (Ruud et al., 2010) were obtained as described in Paper IV.

Statistical analysis

Layout data and information on housing conditions were analyzed descriptively in Paper I. These data were merged with milk yield data, building costs and labour input data in the respective papers. In Paper II "mixed models" in SPSS 17 for windows (SPSS, Inc., Chicago, Ill.) was used analyzing the association between 305 days milk yield and the layout of different barns, using herd as random effect in a two level model. Both simple models including the different explanatory variables one by one together with parity, calving interval and herd as random effect, and a final model including all significant explanatory variables, were created. In Paper III and IV "General Linear Model" (GLM) in SPSS was used in a similar way analyzing herd level data.

Summary of results from individual papers

Paper I

Layouts and space allocation in Norwegian freestall dairy barns.

The mean total cow area (TCA) was 8.37 ± 1.09 m^2 per freestall, ranged from 5.88 to 12.61 m^2, decreased with increased number of stalls and was higher for new buildings compared to rebuilt buildings. The mean freestall area was 2.78 ± 0.18 m^2 per freestall and represented 33.2 % of the TCA. Both alley area and feed bunk space decreased with increasing number of freestall rows. The mean alley area was 3.70 ± 0.63 m^2 per freestall and represented 44.2 % of the TCA. Widths of feed alleys (3.21 ± 0.43 m) and freestall alleys (2.25 ± 0.44 m) varied considerably and a high proportion was below the American recommendations (Bickert et al., 2000). However, only a minor proportion was below the international recommendations (CIGR, 1994). Barns with automatic milking system (AMS) had approximately 1.0 m^2 less milking area per freestall compared to barns with milking parlours. Nearly 25% of the barns had no separation area for maternity and sick cows and even 16 % of new barns had no space for this important cow group. Increased herd size and choosing AMS-systems over traditional parlours were structural factors that reduced building space. However, in several barns space was minimized by decreasing the alley widths and skipping the separation area, which is absolutely not recommendable.

Paper II

Layouts for small freestall dairy barns: effect on milk yield for cows in different parities.

The final statistical model estimates show that only primiparous cows benefit from increased free space allocation by increased milk yield. Milk yield was generally higher in automatic milking system (AMS) barns compared to barns with milking parlours, but not for primiparous cows. Milk yield was higher for all parities for barns using maternity pens or pens for sick cows in accordance with the recommendations. Barns with two or more "dead end alleys" had lower milk yield compared to layouts without dead end alleys. Primiparous cows benefit from water troughs located for easy access and respond by increased milk yield. In 10 % of the barns the water trough capacity was less than 47% of the recommendations, and all parities benefit from a water trough capacity higher than this level. Higher parities had increased milk yield when water trough capacity was more than 80 %. Feed bunk space, number of freestall rows or the location of freestalls had no significant effect on the milk yield.

This study show that increased space and improved access to water is beneficial to primiparous cows, whereas layouts without dead end alleys and improved water capacity is beneficial for all cows in freestall systems.

Paper III
Dairy barn layout and construction: Effects on initial building costs

Plot of the data reveals that construction costs per square meter decreased up to approximately 1250 m^2 while mechanization costs and total building costs decreased up to approximately 1000 m^2. A further increase in building area had only limited effect on the building costs per m^2. Models including explanatory variables showed that milking- and service area was significantly more expensive than other areas. AMS-barns were all together not significantly more expensive than other barns, since the increased mechanization cost is offset by need for less milking area. Farmers remodelling their barns were able to realise a modernized building for a certain herd size for a lower cost compared to a completely new building. The value of own effort varied considerably between projects, and in many cases the value was so low that farmers would be able to find alternative income sources with a higher hourly rate than the model predicts.

Paper IV
Labour input in small cubicle dairy barns with different layouts and mechanization levels.

The required labour input per cow decreased by increased herd size, up to approximately 60 cows. Barns with AMS had the same estimated labour input per cow independent of herd size. For herds with milking parlours the estimated labour input decreased by increasing herd size from 20 to 80 cows. The estimated required labour input was higher for rebuilt barns up to a herd size of 39 cows. The comprehensive variation in labour input indicates that optimizing building layout, developing good management routines and proper mechanization levels, would considerably reduce the required amount of labour.

Results and general discussion

As documented in Paper I, the space allowance (m^2/cow) in small dairy freestall barns (< 100 cows) varies considerably and this variation represents a difference in initial building costs as discussed in Paper III. In freestall housing, many different modules must be considered, and barn layout and stocking density is found to affect dairy cows as documented in Paper II. In addition to effects on the cattle, the space allocation and barn layout may influence the labour required as discussed in Paper IV. The results from the studies included in this thesis emphasise the effect of different space allowance on milk yield, initial building costs and labour required for dairy work.

Herd size

The total cow area (TCA) decreased by increased herd size (Paper I). Dairy barn layouts for small herds seem to be less area efficient, seeing as they must offer the same modules as in bigger herds, and a proper layout is more demanding to design without allocating more space.

Simensen et al. (2010) found that milk yield increased with increasing herd sizes in small freestall dairy barns and was significantly lower than in tie-stall barns for herds up to 27 cows. This effect also seemed to occur in the study presented in Paper II, but when adjusting for other variables, there was no effect of herd size. This indicates that it is not really the herd size, but the building conditions offered by different layouts that contribute to a lower average milk yield in small herds. Probably even more space should have been allocated for the cows on these farms? Morrison et al. (1981) found groups of five cattle to have less daily feed intake than a group of ten cattle with the same space allocated per animal. Petherick et al. (1983) pointed out that the need for space is greater in small groups of animals. This principle is not laid down in the guidelines for dairy cows (e.g. CIGR, 1994; Bickert et al., 2000), but according to the European regulations for dry sows (EEC, 2001) the unobstructed floor area must be increased by 10% for groups of fewer than six pigs. Still, there seems to be no scientific evidence to support this requirement in relation to pigs (Turner et al., 2003).

Reduced building costs per unit by increased herd size are well documented (Hoglund and Albright, 1970; Gjerde, 1996) and the results from Paper III confirm this statement. The total building costs (TBC) decreased rapidly up to approximately 1000 m^2 or a herd size of 55 dairy cows including replacement, milking and feeding facilities, and fits quite well with previous studies (Hoglund and Albright, 1970; Gazzarin and Hilty, 2002).

Herd size may also affect the required labour input per cow (Nygaard, 1977; Auernhammer, 1990; Hedlund, 2008). According to the field observations there is a significant reduction in required labour input up to a herd size of approximately 60 cows (Paper IV). The statistical model suggests that this effect might be present for even bigger herds.

Layout factors

The guidelines describe design of the different modules or “resources” in the freestall system one by one (e.g. CIGR, 1994; Bickert et al., 2000). However, combinations of these modules might be expressed by many different layouts, and furthermore influences the space allocation and how cows react on their local environment.

The details in design of the freestalls may be of great importance for cleanliness and animal welfare (Ruud et al., 2010). Still, this variation in freestall dimensions only has a limited effect on the TCA. The results from Paper I show that in new buildings, freestall sections were usually located parallel to the feed bunk. Alternative locations did not affect the alley area and layouts in typical rebuilt barns did not differ from new buildings. The location of freestalls did not affect milk yield (Paper II) nor the required labour input (Paper IV). In agreement with Graves (1989) the mean alley area was less for three rows than for two and four rows. Number of freestall rows did not affect the milk yield (Paper II). The model results from Paper IV showed that barns with 1-2 freestall rows had significant higher required labour input per cow. The statistical model was adjusted for herd size. One reason for this result might be that small farms have less opportunity to invest in labour-saving mechanization like AMS or automatic feeding

There are many recommendations for space allocation in alleys (e.g. CIGR, 1994; Bickert et al., 2000; Landbruksdepartementet, 2004; DLBR, 2005), yet information about effects on cows is scarce. The variation in space allocated for alleys varied considerably (Paper I), although results from Paper II showed that a general increase in free accessible area (freestall- and alley-area) had no effect on milk yield. The only exception from this was primiparous cows that tended to benefit from increased space allowance by increased milk yield. Reducing the width of alleys to a considerably low level, may cause an increase in number of confrontations and reduced milk yield (Henneberg et al., 1986). According to Paper II the width of alleys had no effect on milk yield, yet the alleys were wider than the alleys tested by Henneberg et.al. (1986).

Several authors state that crossovers should be provided for every 25-40 stalls, and dead end alleys should be avoided (Bickert et al., 2000; Smith et al., 2000). Barns with “dead end alleys” (Figure 8) had less alley area per freestall (Paper I), but an interesting finding in Paper II is that cows in barn layouts with more than one dead end alley had a significant lower milk yield whereas one dead end alley had no effect. Cows seem to cope with one dead end alley, probably because of the possibility of avoiding these sections in the barn. This finding supports the recommendations stating that layouts with dead end alleys should be avoided.

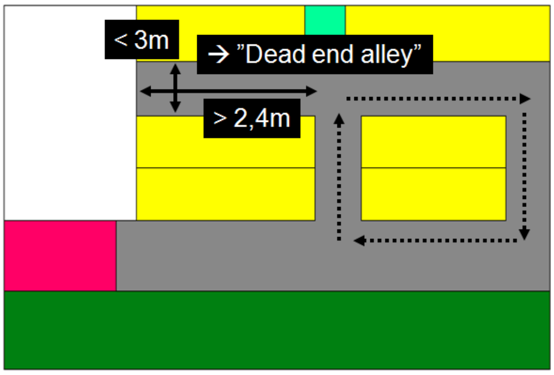

Figure 8: A “dead end alley” was defined as a feed alley or a freestall alley without crossovers in both ends, with a minimum length of 2.4 m and a width of less than 3 m.

Separating dry cows simplify the work by removing non-milking cows from the lactating group. However, the results from Paper II and Paper IV show no effects on milk yield or required labour by separating dry cows. Primiparous cows have earlier been found to benefit from being separated from elder cows by increased feeding time, feed intake and milk yield (Krohn and Konggaard, 1979). In small herds, however, separating primiparous cows is not easily feasible. Interestingly results from Paper II show that primiparous cows benefit from increased free accessible area and water troughs located for easy access. This might be an effect of small groups where subordinated cows have limited possibilities to avoid from dominating cows.

The importance of well designed facilities for special needs cows is emphasized by several authors (Cook and Nordlund, 2004; Graves et al., 2006; Kammel and Graves, 2007), yet data from Norwegian herds show that these areas often are minimized, or even not present. Furthermore, they are often not in practical use (Paper I). This is not only a Norwegian phenomenon. Similar practise is already documented from Canada (Vasseur et al., 2010). Many farmers seem to reduce the initial building costs by minimizing these facilities. The result of this choice is a significant lower milk yield (Paper II) and also a weak tendency of increasing required labour input (Paper IV), in addition to worsen the animal welfare. In total, saving space by skipping the separation area is absolutely not recommendable (Figure 9).

Figure 9: Both cows and farmers benefit from a well designed module for special needs cows.

The TCA enlarged by increased feed bunk space per cow. Furthermore the feed bunk space decreased by increasing number of freestall rows (Paper I) as also pointed out by other authors (Graves, 2000; Mentink and Cook, 2006). Negative behavioural effects, as increased competition and rate of displacements by reducing the feed bunk space, are documented by several authors (e.g. DeVries et al., 2004; Huzzey et al., 2006). The results from Paper II show no effect of feed bunk space on milk yield. Mean feed bunk space per cow was 0.58 m. Friend et al., (1977) observed increased competition by the feed bunk when reducing the space slightly below one eating place per cow (0.6-0.7 m). However, the feed intake was not reduced until the feed bunk space was reduced to below 0.2 m per cow. Olofsson (1999) documented that cows compensate for reduced feed bunk space and increased competition by increased consumption rate. Therefore, it is not surprisingly that feed bunk space did not affect milk yield in the study presented in Paper II.

In average barns with feed stalls allocated 1.0 m wider feed alleys including feed stalls (Paper I). However, feed stalls had no effect on milk yield (Paper II). Adding feed stalls has earlier been found to reduce the competition in front of the feed bunk by forcing cows to initiate contact at the rear of the animal they wanted to displace (DeVries and von Keyserlingk, 2006). Increased feed bunk space without feed stalls also reduced the number of displacements in front of the feed bunk considerably. When optimizing the space allocation, including feed stalls should probably not have the highest priority.

High yielding lactating cows need abundant availability of fresh water (Brouk et al., 2003). Recommendations for water trough capacity describe a certain number of cows per drinking bowl or accessible perimeter of water trough per cow (CIGR, 1994). According to the results in Paper II, the 10 % barns with the lowest water trough capacity had less than 47 % of the capacity described in the guidelines, and this resulted in a significant reduction in milk yield. Higher parities produce more milk, and seem to be most sensitive to water access. It is alarming that a basic resource as water is limited in many barns. Investing in more water troughs is obvious the best measure to take.

In 41% of the barns water troughs were located in the crossovers (Paper I). Crossovers including water troughs must have sufficient space for cows to drink and cross at the same time. In many cases the crossovers were not wide enough for allowing two directional cow travel behind another cow drinking as described by McFarland (2000). Primiparous cows seem to be sensitive for this, and benefit from water troughs located for easy access (on the first freestall row). Bickert et al. (2000) stated that more space and more locations should be provided when primiparous cows are housed with older cows.

Mechanization

The mechanization costs per m^2 as a function of total area was reduced by increased area up to approximately 1000 m^2 (Paper III). The variation in mechanization level was comprehensive and most pronounced among remodelled barns.

An assortment of technical equipments is available for simplifying the dairy work. Milking has traditionally been the most labour intensive part of the work (Auernhammer, 1990; Hedlund, 2008), and still is on most of the farms. The introduction of automatic milking system (AMS), however, has had a great impact on daily working routines, required labour input and barn layouts during the 2000s (Rodenburg, 2004; Svennersten-Sjaunja and Pettersson, 2008). Results from Paper I show that AMS barns in average allocated approximately 1.0 m^2 less space per cow for milking compared to traditional milking parlours (including holding pen, milking parlour / automatic milking unit and return alley). Milking facilities represent high cost areas, and saving space by reducing the milking area has a significant effect on initial building costs (Paper III). The milking robot, however, represents a large investment, annual costs for maintenance must be expected to increase and the economic life is limited. In Paper IV an estimate of reduced required labour input on AMS-barns is discussed. The labour input per cow was not affected by herd size in AMS barns (Paper IV), whereas barns with milking parlours seemed to choose milking parlours with increasing capacity by increased herd sizes as described before (Jakobsson, 2000; Schick, 2000). Hence, the difference between milking parlours and AMS decreased by increasing herd size.

According to Paper II, the milk yield was significantly higher in herds with AMS (Figure 10) and this is supported by the conclusion in the review article of Svennersten-Sjaunja and Pettersson (2008). In Paper II no such effect could be seen for primiparous cows. Spolders et al. (2004) found that primiparous cows visited the milking unit more often than multiparous cows, but the increased milking frequency had no effect on milk yield. Another statement that supports our findings is that cows of low social rank, which primiparous cows often are, spend more time waiting in line in front of the milking unit (Melin et al., 2006).

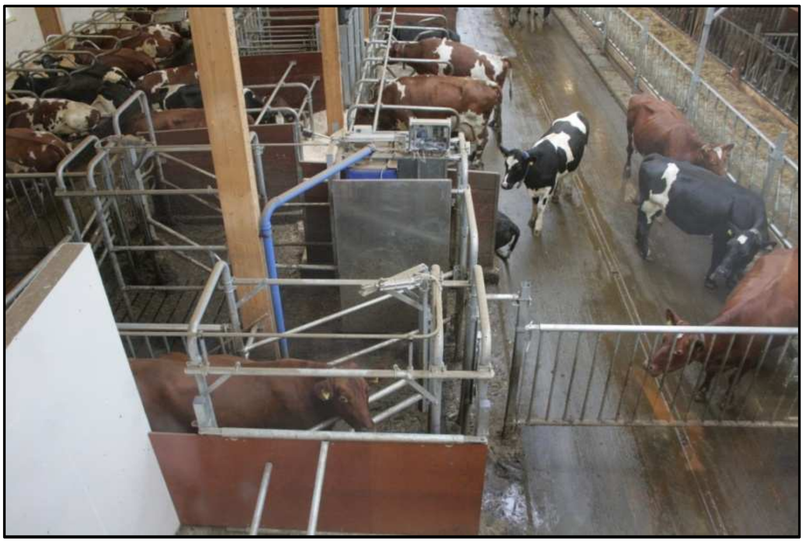

Figure 10: In general AMS barns lead to increased milk yield

In Norway, manure handling normally is based on slatted floors or mechanized by manure scrapers. Therefore there is limited variation in manure handling systems on the farms included in the papers in this thesis, and the results from Paper IV show no effect on the labour required.

The way of feeding roughage did not affect the labour input per cow (Paper IV). Different feeding systems demand unequal amount of work. However, the feeding method will normally be dimensioned in proportion to the herd size. On farms with large herds the feeding systems often are much more efficient than on farms with small herds, and this may be the reason why the estimated labour input did not differ between roughage feeding systems.

New vs. remodelled facilities

An alternative to building new separate barns is to remodel and expand present barns. By remodelling their facilities, many farmers were able to attain a modernized building of a certain size for a lower cost, compared to a completely new building (Paper III). The required labour input, however, was higher in remodelled buildings (Paper IV) up to approximately 40 cows. This is supported by earlier studies emphasizing that remodelled barns must expect lower functionality compared to new buildings (Ekelund and Dolby, 1993; Bewley et al., 2001a). Saving money by decreased initial costs seem to result in building conditions that demand more labour input, yet remodelling might also give attractive returns compared to more capital-intensive investments in new facilities as stated by Lazarus et al., (2003).

In new buildings more space was allocated for cows compared to remodelled buildings (Paper I). Remodelled barns often include layout conditions (e.g. dead end alleys) that contribute to decreased milk yield (Paper II). Many farmers have existing barns with a quite high technical value and remodelling might be a reasonable choice. In many cases a completely new building is unattainable due to high investment costs. However, layouts and space allocation in remodelled barns must meet the same quality criteria as new facilities.

Building- constructions and costs

There were comprehensive variations in construction costs, also among barns for approximately same herd sizes (Paper III). The geometry of buildings caused some of this variation. Barns with a small base need more surface area of the superstructure (roof and walls), and is one of the main reasons for decreased construction costs by increased herd size.
Service rooms in addition to milking facilities represented areas of higher initial cost per m^2 (Paper III), and barns with a high share of such area had an increased mean building cost per m^2.
The amount of manure storage influenced the construction costs per m^2 (Paper III). In many barns there was just a short term storage included in the building project while others had quite big storages to take care of manure from adjacent rooms. Even though the results in Paper IV showed that tower silos was associated with higher labour input when adjusting only for herd size, there were no significant variation in the final model when all other significant explanatory variables were taken into account.

Using posts for supporting the main construction was expected to reduce building costs. The figures in Paper III did not support this assumption. Types of construction materials in floors and roofs did neither not significantly affect the construction costs. A number of different materials were used, and it seems not to be obvious which materials that are the most preferable. Geographically conditions may have affected this result. According to Paper III the construction costs were significantly lower in typical husbandry regions, and there were correlation between regions and main construction material. A similar situation was much earlier described by Albright (1964). Cost competitiveness and competence might be the reason for this variation, and may also have affected types of materials used.

According to previous studies, initial building costs were expected to be slightly lower for uninsulated barns (Berg, 1995; Sällvik, 2003). As discussed in Paper III no significant difference in total building costs between insulated and uninsulated barns was found, probably because uninsulated buildings were very similar to insulated buildings. Often they had quite expensive controlled natural ventilation, and in sum they did not have significantly lower costs. More open buildings would probably have resulted in lower costs (Simon et al., 2007). The milk yield was lower in cold buildings with natural ventilation (Paper II). Considering the low LCT (Lower Critical Temperature) for high yielding dairy cows (Young, 1981) this finding was unexpected. Comparable production results in cold buildings have earlier been found (Zähner et al., 2004). It is reasonable to assume that the result presented in Paper II is influenced by other conditions on these farms that were not analyzed in the paper. Examples are management routines, feeding systems etc.

Farmers own effort during the building process contributed to reduced costs. However, the calculated value of this work was just 50 % of the actual salary scale for farm work in Norway. It must be taken into account that farmers did not have to pay tax for their own effort as they have to for employed work. Furthermore, a great involvement in the building process might be unprofitable if the farm production is suffering. Aschan and Stockzelius (1997) stated that many farmers experienced reduced milk yield during the building process. In sum, farmers must consider the alternative value for their own effort in the building process; whether they go for employed work outside the farm or if they decide to prioritize the ordinary farm work.

Labour efficiency

In addition to explanatory variables for the variation in labour input described above, it was interestingly to observe the effects of farmers' attitude toward animals, and the cleanliness score of cows (Paper IV). Farmers who disagree in the statement "animals experience physical pain as humans do" had a weak tendency to spend less time on the dairy work. This might reflect the interests of the farmers and how they prioritize their work. However, the volume of the work does not necessarily reflect the quality. Furthermore herds with cleaner cows tended to be associated with a higher required labour input. Proper cleaning and provision of sawdust in cubicles takes additional time, but will also contribute to cleaner cows (Ruud et al., 2010).

Interestingly the required labour input per cow decreased by increased milk yield. It is reasonable that farmers with high yielding herds have more focus on management and efficient work. High yields are correlated with healthy cows, which also will reduce the required labour input.

Methodological considerations

The studies done as basis for this thesis includes a large number of farms, and the comprehensive field work needed was possible since this work was part of the bigger project "Freestall barns for dairy cattle". In addition, the unique recording system for dairy herds in Norway (NDHRS) made the analysis of correlations between building conditions and milk yield possible.

An alternative approach to analysing effects of different layouts is to study a limited number of barns more thoroughly and include behavioural studies in the analysis. However, access to data as mentioned above gave us a unique opportunity to study the topic by using quantitative methods and statistical modelling.

Concluding remarks

Space allocated for dairy cows in freestall barns varies considerably and this variation has a significant effect on initial building costs. Dairy cows kept in freestall barns are affected by a number of housing conditions. Low water trough capacity, lack of facilities for special needs cows and layouts with dead end alleys all resulted in decreased milk yield. Primiparous cows seem to be more sensitive about reduced space allocated in front of resources.

Decreased space allocation and required labour input, increased mechanization costs and milk yield are all effects of installing AMS. This innovation is of particular interest in high cost countries like in Scandinavia. However, the total economy of investing in AMS is not clarified.

The required labour input per cow decreased by increasing herd size, and was higher for remodelled than for new barns. Building new or remodelling facilities, building costs, required labour input and animal welfare must be considered.

Practical application

Designing layouts for new or remodelled facilities for dairy cows, abundant space allocated for water troughs, pens for special needs cows and crossovers enough to avoid dead end alleys must be considered. By including these facilities in an optimal way, the total cow area and building costs will increase. Reducing space allowance for important modules in the layout must be avoided. Efforts for reducing building costs should rather be provided on keeping construction costs low, probably including outdoor yards in the layout.

Remodelled barns in average demand more labour input per cow and a proper plan is needed to achieve facilities that is not characterized by compromises.

Suggestions for further research

The present studies have revealed the importance of considering the different groups of cows in a herd. Primiparous cows and different kinds of special needs cows benefit from being separated from the rest of the herd. Further research is needed to develop layouts and housing conditions that make this possible in small herds. Flexible pens for special needs cows is one example. Using the technology from smart-gates to guide primiparous cows to their own module in the barn is another example.

Furthermore design of alleys need to be studied in order to examine behavioural effects of different space allocated for alleys and crossovers. The economy of investing in AMS under different conditions also needs to be studied.

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Eratum

According to the version delivered for review, this final version of the PhD-thesis is revised on the following points:

Page 5	Rewritten sentence:	Primiparous cows seem to be more sensitive about reduced space allocated and access to resources.
Page 12	Rewritten sentence:	With feed stalls in front of the feed bunk (i.e. partitions between adjacent cows) this effect was more pronounced, yet feed stalls demand additional space (DeVries and von Keyserlingk, 2006).
Page 21	Rewritten sentence:	Milk yield was higher for all parities for barns using maternity pens or pens for sick cows in accordance with the recommendations.
Page 24	Rewritten sentence:	One reason for this result might be that small farms have less opportunity to invest in labour-saving mechanization like AMS or automatic feeding.
Page 25	Figure 8 is added. Figure text:	Figure 8: A “dead end alley” was defined as a feed alley or a freestall alley without crossovers in both ends, with a minimum length of 2.4 m and a width of less than 3 m.
Page 26	New figure number	Figure number changed from 8 to 9.
Page 28	Rewritten sentence:	Results from Paper I show that AMS barns in average allocated approximately 1.0 m^2 less space per cow for milking compared to traditional milking parlours (including holding pen, milking parlour / automatic milking unit and return alley).
Page 29	New figure number	Figure number changed from 9 to 10.
Page 31	Rewritten sentence:	Farmers own effort during the building process contributed to reduced costs. However, the calculated value of this work was just 50 % of the actual salary scale for farm work in Norway.
Page 44-45	Added section	Acknowledgement is added.

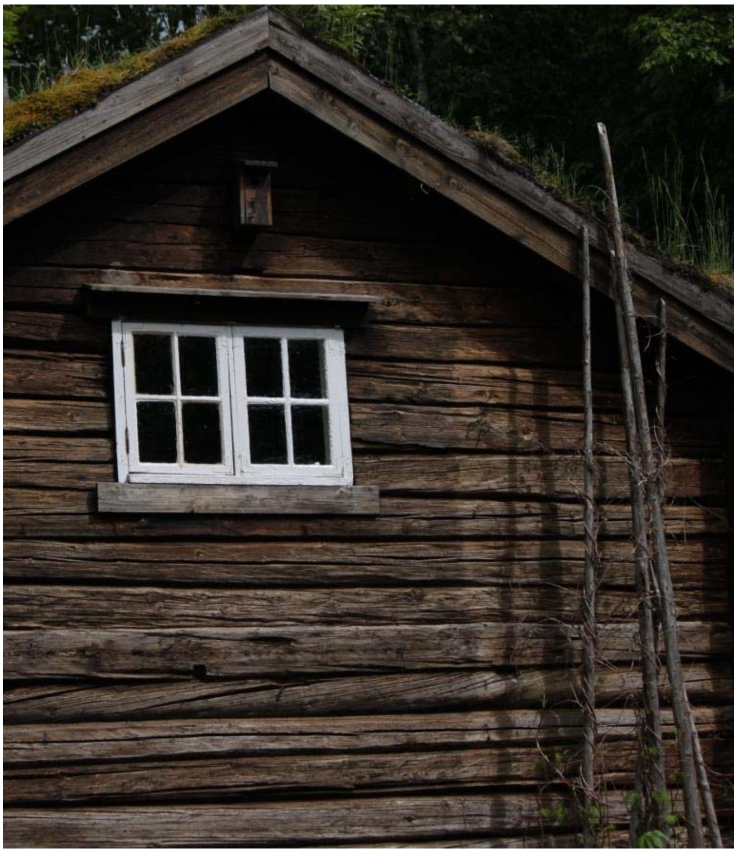

Photo: Håvard Næss

Life can only be understood backwards; but it must be lived forwards.

Soren Kierkegaard

Layouts and Space Allocation in Norwegian Freestall Dairy Barns

G. Naess, K. E. Bøe

Abstract. *The objectives of this article are to describe layouts and space allocation within Norwegian freestall dairy barns. Layouts from 207 Norwegian freestall barns, 94 new and 113 rebuilt, constructed during 1995-2005, and with a mean of 42.0 ±16.5 freestalls for lactating cows, were obtained and the areas dedicated for milking cows were analyzed. The mean total cow area (TCA) was 8.37 ± 1.09 m² per freestall, ranged from 5.88 to 12.61 m², decreased with increased number of stalls, and was higher for new buildings compared to rebuilt buildings. The mean freestall area was 2.78 ± 0.18 m² per freestall and represented 33.2% of the TCA. Both alley area and feed bunk space decreased with increasing number of freestall rows. The mean alley area was 3.70 ± 0.63 m² per freestall and represented 44.2% of the TCA. Widths of feed alleys (3.21 ± 0.43 m) and freestall alleys (2.25 ± 0.44 m) varied considerably, and a high proportion was below the American recommendations. However, only a minor proportion was below the international recommendations. Barns with automatic milking systems (AMS) had approximately 1.0 m² less milking area per freestall compared to barns with milking parlors. Nearly 25% of the barns had no separation area for maternity and sick cows, and even 16% of new barns had no space for this important group of cows. Increased herd size and choosing AMS over traditional parlors were structural factors that reduced building space. However, in several barns, space was minimized by decreasing the alley widths and skipping the separation area, which is absolutely not recommendable.*

Keywords. *Design, Freestall housing, Layout, Space.*

Dairy cattle in small herds have traditionally been housed in tie-stall barns, whereas farmers with more than 80 to 100 cows generally have adopted freestall housing (Graves, 1989). Even though the building costs are lower for small tie-stall barns (Reichel, 2005), freestall barns are probably more labor efficient (Boyd, 1969; Stahl et al., 1999) and are associated with improved cow health (Ekesbo, 1966; Bakken et al., 1988). Milk yield in freestall barns seems to be at the same level as in tie-stall barns (Heizer et al., 1953; Konggaard, 1977) or somewhat lower (Simensen et al., 2007). In Scandinavia, a gradual expansion of herd size by remodeling existing buildings to freestalls and parlor systems has been common in order to keep building costs low (Ekelund and Dolby, 1993). However, the functionality of these facilities is questionable. Lazarus et al. (2003) argued that a more gradual expansion can also offer attractive returns compared to more capital-intensive new facilities.

Compact floor plans including covered systems with indoor feeding (Graves, 1989) are used more often in colder regions due to higher construction costs. According to Graves (1989), there was a trend in the U.S. in the 1970s toward minimizing housing space per animal in an attempt to reduce building costs, and this trend seemed to continue in Norway in the 1980s. Minimizing space involves both reduced feed and alley space and overcrowding (more than one cow per freestall). When reducing space to a very low level, studies show negative effects on productivity and behavior (feed bunk space: Friend et al., 1977; DeVries et al., 2004; number of freestalls per cow: Bowell et al., 2003; Fregonesi et al., 2007; alley width: Henneberg et al., 1986). Recent recommendations (Bickert et al., 2000; Graves, 2000; DLBR, 2005) suggest much more space than these levels. Except for Wierenga et al. (1985), no documentation from controlled studies demonstrates benefits in animal comfort or productivity with increased space. However, field observations indicate that allowing more space is common in high-producing herds (Graves, 1989).

The number of freestall rows along a feedline will influence the total area and the available feed bunk space per cow. Housing designs with three rows of freestalls cut building space per freestall and may therefore reduce building costs. Such layouts do not allow all animals to be located or locked up at the feed barrier at the same time. If animals are isolated in the freestall row, then there are insufficient freestalls for all cows compared to housing designs with two rows of tail-to-tail freestalls (Graves, 2000). Freestall barn layouts seem to have changed little over the 1980s and 1990s. However, the introduction of robotic milking or automatic milking systems (AMS) has had a great impact on layouts and the reduction of space for milking during the 2000s (Rodenburg, 2004).

There are different groups of “special needs” cows that demand specific attention and extra space (Graves et al., 2006). A separation area should be designed for each particular purpose, but in small herds some of the different cow groups

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might be consolidated (Kammel and Graves, 2007). The area required for transition cows varies with the distribution in calving time and herd size (Stone, 2000).

There are different approaches to optimize the utilization of the layout. Some researchers have used algorithms and neural network methods to simulate an optimized layout (Halachmi et al., 2002; Fernandez et al., 2006; Marco et al., 2008), whereas others have studied the on-farm effects or theoretical benefits of choosing particular building layouts and configurations (Bewley et al., 2001).

The objectives of this article are to describe layouts and space allocation within recently built or remodeled Norwegian freestall dairy barns.

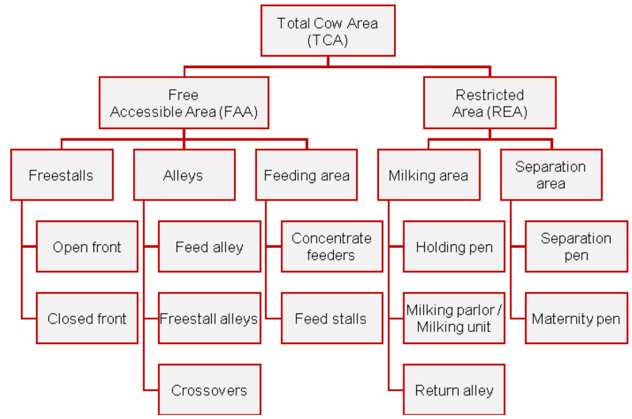

Figure 1. Definition of different areas for lactating cows.

Materials and methods

The Herds

This study was part of a larger descriptive and cross-sectional project on freestall housing. From a questionnaire sent to all dairy advisers in Norway, a list of 2,400 presumably known freestall-housed herds in Norway was obtained. These farmers received a questionnaire covering several aspects of their freestall housing system. To be included in the final study, farmers had to fulfill our inclusion criteria: volunteer to participate, have a herd size >20 standardized cow years based on the year 2005 (cow year = number of days from first calving to culling within one year, divided by 365), and have a barn built in the years 1995 to 2005. As we expect some housing systems to be common in the future, all barns with AMS (n = 44), with solid concrete floors (n = 105), or with rubber solid floors (n = 24) in the alleys were included in the study barns. Traditionally, freestall barns in Norway have been constructed with slatted floors, and such buildings were only included if they were located in the same municipality as farms mentioned above. The final database included 232 free-stalled dairy herds located all over Norway. Due to missing information about floor plans, the final material in this study included 207 herds.

Observations

During the period from September 2006 until May 2007, all the barns were visited once by trained observers. Farmers were asked to provide detailed drawings used during the barn-building process. Approximately 80% of the farmers were able to provide such drawings. On these farms, all the main dimensions of the building were measured using an electronic measuring device (Leica Disto type A3, 2006 version, Leica Geosystems, St. Gallen, Switzerland) to ensure that the drawings were correct. For the rest of the buildings, dimensions for indoor length, width and height of the building, alleys, freestalls, pens etc., were measured using the same electronic measuring device. For some of the freestall rows along the outside wall, the head zone was combined with a walkway, and it was necessary to define the maximum length of the freestall. In this study that dimension was set to be 2.8 m. In addition, photographs of the barns were taken systematically, both inside and outside, using a digital camera.

On the basis of the drawings, measurements, and pictures, an accurate floor plan was created using the computer-aided design software VectorWorks Architect (2007 version, Columbia, Md., Nemetschek North America, Inc.) for each barn. The total cow area (TCA) in the barn was defined as the area allocated for lactating cows excluding the feed table (fig. 1), and this area was divided into free accessible area (FAA) and restricted area (REA).

The FAA included freestalls, alleys (feed alley, freestall alleys, and crossovers), and feeding area (concentrate feeders and feed stalls). The feed alley was the alley closest to the feed barrier, while freestall alley 1 was the first alley next to the feed alley, and freestall alley 2 was farther away from the feed alley. Feed stalls included the partitions that separate adjacent cows while eating, as described by DeVries and von Keyserlingk (2006). The REA included the milking area (holding or collecting area, and milking parlor/automatic milking unit, including support space and return alley) and separation area (separation and maternity pens). The holding area was the waiting area in front of the milking parlor or milking unit. The separation pen was meant for isolating sick cows, and the maternity pen was dedicated for the period around calving and did not include dry cows (fig. 2). In addition, dead-end alleys were defined as feed alleys or freestall alleys without crossovers in both ends, with a minimum length of 2.4 m and a width of less than 3.0 m.

VectorWorks Architect includes a function that allows automatic calculation of the size (in m^2) of the different areas (freestalls, feeding area, alleys, milking area, and separation area). Area data were exported to a spreadsheet for comprehensive analyses. In order to avoid an effect of management, especially stocking density (number of cows per freestall), the unit of measure presented in the analyses was m^2 per freestall. Hence, we assumed that there was one cow per freestall.

Statistical analyses were performed using SPSS (ver. 15 for Windows, Chicago, Ill.: SPSS, Inc.) One-way analysis of

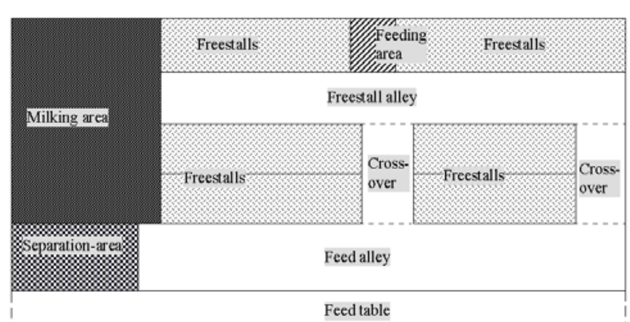

Figure 2. Example of a freestall barn layout.

variance was used for testing the effect of number of freestall rows on alley area and crossover area, milking system on milking area and alley area, and building type on separation area. The Bonferroni test was used for testing differences between means. The Pearson correlation coefficient was used for testing the correlation between the following variables: TCA and number of freestalls, alley width and alley area, crossover area and alley area, and feed bunk space and alley area.

Results

Ninety-four barns were new buildings (mean year of building 2003), and 113 were rebuilt buildings (mean year of rebuilding 2002). The mean number of freestalls for lactating cows was 42.0 ±16.5 (mean ±SD) for all buildings, 47.3 ±17.7 for new buildings, and 37.7 ±14.0 for rebuilt buildings. The total cow area (TCA) varied from 5.88 to 12.61 m^2 per freestall, and the free accessible area (FAA) varied from 4.83 to 8.91 m^2 per freestall (table 1). The mean number of cows per freestall was 0.93 ±0.14. In 25.1% of the barns, there was more than 1.0 cow per freestall, and in 74.9% there was 1.0 or less. Generally, the TCA decreased with increasing number of freestalls ($r = -0.284$, $p < 0.01$; fig. 3), and this was more pronounced for new barns ($n = 94$, $r = -0.446$, $p < 0.01$) than for rebuilt barns ($n = 113$, $r = -0.317$, $p < 0.01$).

The freestall area represented 33.2% of the TCA, and there was only a minor variation between barns (table 1). As the variation in stall width between stall partitions was quite small (mean = 1.14 m, range = 1.05 to 1.20 m), the variation in freestall area can mainly be explained by the variation in freestall length. For stalls with closed fronts (against a wall) the length ranged from 2.00 to 2.80 m, and for open front stalls (in double rows) the length ranged from 1.90 to 2.60 m.

The feeding area represented only 2.0% of the TCA. The majority of the barns ($n = 189$) did not have feed stalls, and in these barns the mean feeding area was only 0.10 m^2 per freestall, whereas the feeding area in barns with feed stalls ($n = 18$) was 0.82 m^2 per freestall. Mean length of feed stalls was 1.58 m. Twenty barns had neither feed stalls nor concentrate feeders, and consequently they had no feeding area at all. Barns without feed stalls had wider feed alleys (mean = 3.21 m) compared to barns with feed stalls (mean = 2.63 m), but the mean width of feed alleys and feed stalls added up to 4.21 m, which is actually 1.00 m wider than for barns without feed stalls.

Table 1. Distribution of the total cow area (TCA).

Area[a]	Size (m^2 per freestall, mean ±SD)	Proportion of TCA (%)	Range (m^2 per freestall)	CV (%)
Freestalls	2.78 ±0.18	33.2	2.32-3.27	6.5
Feeding area	0.17 ±0.21	2.0	0.0-1.06	126.6
Alleys	3.70 ±0.63	44.2	2.17-5.44	17.0
FAA	6.65 ±0.68	79.5	4.83-8.91	10.2
Milking area	1.30 ±0.63	15.5	0.21-4.04	48.6
Separation area	0.42 ±0.37	5.0	0.0-1.93	87.6
REA	1.72 ±0.72	20.5	0.33-5.34	42.0
TCA	8.37 ±1.09	100.0	5.88-12.61	13.0

[a] FAA = free accessible area, and REA = restricted area.

The alleys represented 44.2% of the TCA (range = 2.17 to 5.44 m^2 per freestall; table 1). Due to a large difference in feed alley width between barns with and without feed stalls, and because the number of barns with feed stalls was quite small, these barns were excluded from further analysis of the alleys.

Based on the freestall location, the barns were categorized into four different groups (fig. 4). The alley area in barns with freestalls parallel to the feed bunk oriented at one side of the feed table (A in fig. 4; $n = 109$) was 3.71 ±0.56 m^2, while in barns with freestalls oriented on both sides of the feed table (B in fig. 4; $n = 11$) it was 3.82 ±0.45 m^2. For barns with freestalls in a separate section perpendicular to the feed bunk (C in fig. 4; $n = 28$) or in the end of the feed table (D in fig. 4; $n = 11$), the mean alley area per freestall was 3.75 ±0.87 m^2 and 3.75 ±0.75 m^2, respectively. Thirty barns could not be grouped into any of the defined categories. According to these figures, there was no effect of freestall location on alley area. Freestall location A was typical for newly built barns, while B, C, and D were typical for rebuilt barns.

Barns with one freestall row had less space for alley area, but there was no significant difference between layouts with

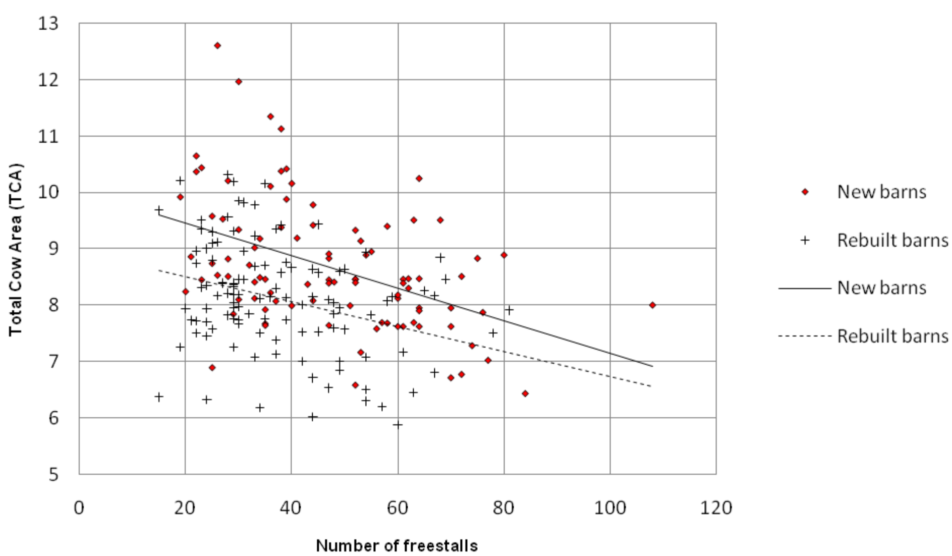

Figure 3. Total cow area (TCA) as a function of the number of freestalls ($n = 207$).

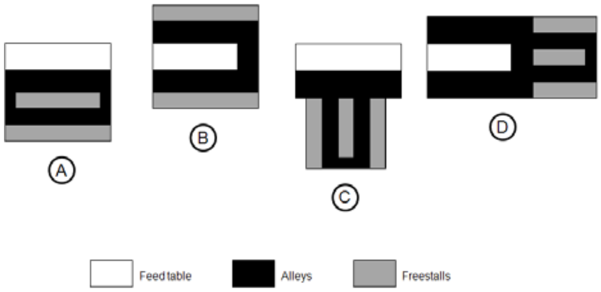

Figure 4. Different location of freestalls: (A) parallel to the feed bunk oriented at one side of the feed table, (B) parallel to the feed bunk oriented at both sides of the feed table, (C) perpendicular to the feed bunk, and (D) in the end of the feed table.

different numbers of freestall rows (table 2). However, looking at new barns with freestall location A, three rows provided cows significantly less space than two rows (3.58 m^2 vs. 4.05 m^2, $p < 0.05$), while there were no significant differences between two and four rows or between three and four rows.

The mean feed alley width was 3.21 m, and it was only marginally wider in new barns (table 3). The width of the feed alley ($r = 0.158$, $p < 0.05$) and freestall alley 1 ($r = 0.147$, $p < 0.05$) both contributed to a significant increase in alley area. For the width of freestall alley 2, this was not the case.

In 58 (30.7%) of the buildings without feed stalls, the feed alley width was less than 3.0 m. Freestall alley 1 was less than 2.0 m in 38 (21.1%) buildings and greater than 2.5 m in 28 (15.6%) buildings. For freestall alley 2, the corresponding number of buildings was 15 (21.7%) and 5 (7.2%).

For new barns, farmers built crossover areas that nearly doubled as the number of freestall rows increased from two to three and four rows (table 4). However, an increase in crossover area with increasing numbers of freestall rows was not chosen by farmers rebuilding their barns.

The crossover area, expressed as a proportion of alley area, increased with increasing number of stalls ($n = 171$, $r = 0.249$, $p < 0.01$) and was greater for barns with location A layouts (fig. 4) compared to locations C and D ($p < 0.01$). Crossover width was $\leq$1.00 m for 18.3% of the crossovers (typical for one cow passage and gates in AMS), 19.7% were between 1.00 and 1.60 m, while 62.0% of the crossovers were $\geq$1.60 m wide (designed for two or more cows). Forty-one percent of the barns had waterers in the crossovers, and these crossovers were generally wider than crossovers without waterers.

Barns with dead-end alleys had less alley area per freestall. Mean alley area per freestall was 3.89 $\pm$0.63 m^2 (n = 92) for barns with no dead-end alleys, while for barns with one dead-end alley and two or more dead-end alleys, the mean alley area per freestall was respectively 3.59 $\pm$0.55 m^2 ($n = 47$, $p < 0.01$) and 3.60 $\pm$0.64 m^2 ($n = 50$, $p < 0.05$).

The mean linear feed bunk space was 0.59 m per freestall (range = 0.26 to 1.05 m per freestall), and in 67.7% of the barns it was less than 0.70 m per freestall. As the linear feed bunk space increased, the size of the alley area increased significantly (fig. 5), and this was more pronounced in new buildings ($r = 0.48$, $p < 0.001$) than in rebuilt buildings ($r = 0.40$, $p < 0.001$). The feed bunk space decreased significantly when the number of freestall rows increased from two to four ($n = 174$, $r = -0.394$, $p < 0.001$).

The mean size of the milking area was 1.48 m^2 per freestall (range = 0.50 to 4.04) for milking parlors ($n = 170$) and only 0.46 m^2 (range = 0.21 to 1.14) for AMS ($n = 37$). When we compared AMS barns with equally sized barns with milking parlors, the difference was about the same (table 5). The mean milking area was significantly larger ($p < 0.05$) in AMS barns with free cow traffic (0.35 m^2 per freestall $\pm$0.10) than in AMS barns with forced or semiforced cow traffic (0.51 $\pm$0.22 m^2 per freestall). However, adding up alley area and milking area, there was no significant difference ($p > 0.10$) between free cow traffic (4.04 $\pm$0.47 m^2 per freestall) and forced or semiforced cow traffic (3.87 $\pm$0.40 m^2 per freestall).

The separation area represented only 5% of the TCA (table 1). In 24.2% of all barns, and even in 16% of new barns, there was no separation area. In barns with a separation area, the mean size was 0.56 m^2 per freestall (range = 0.12 to 1.93 m^2 per freestall), which represented one 10 m^2 pen per

Table 2. Alley area for barns with a different number of freestall rows.

	Number of Freestall Rows				
	1	2	3	4	$\geq$5
All barns					
Number of barns (n)	3	59	70	45	12
Mean alley area (m^2)	3.27 ±0.99	3.83 ±0.69	3.72 ±0.58	3.68 ±0.61	3.80 ±0.61
New built barns, freestall location A					
Number of barns (n)	--	18	38	10	--
Mean alley area (m^2)[a]	--	4.05 b ±0.65	3.58 a ±0.49	3.71 ab ±0.27	--

[a] Means followed by different letters differ significantly ($p < 0.05$).

Table 3. Width of alleys in the free accessible area (FAA).

	Feed Alley	Freestall Alley 1	Freestall Alley 2
All barns			
Number of barns (n)	189	180	69
Mean alley width (m)	3.21 ±0.43	2.25 ±0.44	2.12 ±0.30
New built barns, freestall location A			
Number of barns (n)	66	64	11
Mean alley width (m)	3.26 ±0.28	2.26 ±0.25	2.34 ±0.23

Table 4. Mean crossover area for a different number of freestall rows.[a]

	Number of Freestall Rows				
	2	3	4	$\geq$5	Total
All barns					
Number of barns (n)	48	67	45	11	171
Crossover area / alley area (%)	7.13 b ±2.97	10.98 c ±4.96	10.16 c ±4.72	6.55 ab ±3.16	9.40 ±4.63
Crossover area / freestall (m^2)	0.29 ab ±0.14	0.40 c ±0.20	0.38 ac ±0.19	0.25 a ±0.12	0.36 ±0.18
New barns					
Number of barns (n)	19	42	15	1	77
Crossover area / alley area (%)	7.34 a ±2.79	13.46 b ±3.94	13.91 b ±4.11	10.50 ± --	12.00 ±4.55
Rebuilt barns					
Number of barns (n)	29	25	30	10	94
Crossover area / alley area (%)	7.00 ±3.12	6.82 ±3.50	8.28 ±3.84	6.16 ±3.01	7.27 ±3.48

[a] Means in the same row followed by different letters are significantly different ($p < 0.05$).

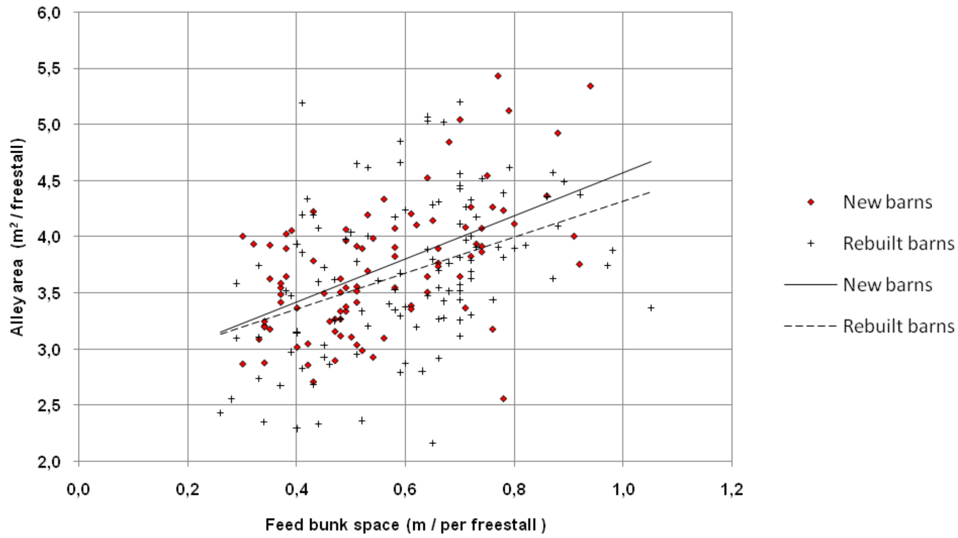

Figure 5. Mean alley area per freestall for different feed bunk space per freestall (*n* = 189).

Table 5. Milking area per freestall for two different milking systems.

	Milking Parlor	AMS
All barns		
Number of barns (*n*)	170	37
Mean milking area (m^2 per freestall)	1.48 ±0.54	0.46 ±0.20
Barns between 30 and 84 freestalls		
Number of barns (*n*)	111	37
Mean milking area (m^2 per freestall)	1.43 ±0.48	0.46 ±0.20

18 cows. New barns had a significantly ($p < 0.0001$) larger separation area per freestall (0.68 ±0.38 m^2) than rebuilt barns (0.43 ±0.18 m^2).

Discussion

The present study showed that there was a large variation in the amount of space allocated for lactating cows in freestall systems (5.9 to 12.6 m^2 per freestall). With increasing number of freestalls, i.e., increasing herd size, the total cow area (TCA) decreased, especially in new buildings. Barns for smaller herds are often rebuilt, usually in combination with adding a new section. It is reasonable to assume that it is easier to optimize the layout in new and larger buildings. However, the TCA was generally larger for new barns than for rebuilt barns, probably, and hopefully, because farmers were more aware of the importance of adequate space when planning new dairy facilities. This is in accordance with the trend pointed out by Graves (1989) that new buildings tend to provide greater space.

As the variation in freestall width was quite small, the variation in freestall area must be due to the variation in freestall length. Some of the freestalls were actually shorter than the recommendations (Anderson, 2008), whereas the freestall length in some barns was extremely long because the head space also functioned as a walkway for stockpersons. Unless dimensions below the recommendations are chosen, there is scarce potential for reducing TCA by minimizing the freestall area. Concentrate feed dispensers occupied a rather small area (0.1 m^2 per freestall), while barns with feed stalls had a much larger feeding area (0.82 m^2 per freestall). Even though DeVries and von Keyserlingk (2006) reported that feed stalls reduced the number of displacements at the feed bunk, one cannot conclude that feed stalls justify the increased building costs, especially since equivalent feed bunk space without feed stalls reduced displacements almost similarly.

In the present study alleys represented a major part of the TCA (44.2%). The mean area was 3.7 m^2 per freestall, which is more than Zeeb et al. (1988) defined as a minimum space needed per cow for social distance and less than the Danish recommendations for activity area of 4.0 m^2 per freestall (DLBR, 2005). Limited space for animals has been shown to lead to lower weight gain for cattle (Ingvartsen and Andersen, 1993). To our knowledge, information on the effect on milk production is scarce, even though high-producing herds seem to be provided more space (Graves, 1989). Rather than the total alley area, most recommendations are linked to the width of alleys and crossovers, feed bunk space, etc. (Bickert et al., 2000; Graves, 2000).

In new buildings, freestall sections were usually located parallel to the feed bunk. Alternative locations did not affect the alley area, and typical rebuilt barns did not differ from new buildings. In agreement with Graves (1989), the mean alley area was less for three rows than for two and four rows. However, feed bunk space decreased with increasing number of freestall rows, as also pointed out by other authors (Graves, 2000; Mentink and Cook, 2006). Generally, feed bunk space increased as the mean alley area per freestall increased. For 67.7% of the barns, feed bunk space per freestall was less than 0.70 m, which is the recommended space for a typical 600 kg Norwegian cow when access to feed is restricted (CIGR, 1994). Less space means that all animals could not eat simultaneously and might result in more competition at the feed bunk (Huzzey et al., 2006; Mentink and Cook, 2006).

In the current study, the mean width of the feed alleys was 3.21 m, which corresponds quite well to the space needed for two cows to pass each other behind another cow standing in front of the feed bunk (Konggaard, 1982; CIGR, 1994) but still quite narrow compared to American recommendations (3.05 to 4.27 m; Bickert et al., 2000, Graves, 2000). More critical was the fact that in 31% of the barns, the feed alley width was below 3.0 m, although no research seems to document the negative effect of narrow feed alleys. The mean width of freestall alley 1 and freestall alley 2 was less than recommended by Graves (2000) and DLBR (2005), even though it was greater than the CIGR recommendations (1994). However, 21% of the freestall alleys were less than 2.0 m wide. Henneberg et al. (1986) showed that two cows passing each other with contact, cows yielding by entering a freestall, and cows queuing in the alley increased when the alley width was reduced from 2.00 to 1.60 m. These parameters increased further when the alley width was reduced to 1.20 m. Milk yield was significantly reduced when the alley width was reduced from 2.00 to 1.20 m.

Smith et al. (2000) emphasized that reducing the number of crossovers limits the cows' access to feed and water. In the present study, the crossover area was greater for new buildings than for rebuilt buildings. Typical rebuilt buildings had the freestalls located in a designated section, and hence the need of crossovers was limited. Forty-seven percent of the barns had layouts with one or more dead-end alleys, and generally these barns also had lower alley area per freestall. Dead-end alleys allow a boss cow to control access and should definitely be avoided (Graves, 2000).

In barns with AMS, the milking area was significantly less than for barns with traditional milking parlors. This contributes to making AMS an interesting system for herd sizes that match the capacity of a milking robot.

Maybe not surprisingly, but still alarming, was the fact that nearly 25% of the barns had no space for separating maternity and sick cows. In addition, among the barns that had such an area available, the size of this area was quite small. According to Kammel and Graves (2007), it is easier to design and run a large-scale section for special needs cows in larger herds, but in smaller herds there also must be a minimum space for this very important part of the herd. In small Norwegian herds, calving time is often concentrated; hence, the special needs pens should be dimensioned for the number of calvings expected in the busiest period.

Conclusions

The variation in total cow area (TCA) was considerable, and there was more space allocated for cows in new buildings compared to rebuilt buildings. The width and length of freestalls in most barns were in accordance with approved recommendations; hence, unless dimensions below the recommendations are chosen, the potential for saving space is minimal. In general, increasing herd size and thereby the number of freestalls and choosing AMS systems over traditional parlors were structural factors that reduced building space. However, in several barns, space was saved by decreasing the alley widths and skipping the separation area, which is absolutely not recommendable.

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As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality.

Albert Einstein

Layouts for small freestall dairy barns: effect on milk yield for cows in different parities.

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ABSTRACT

Freestall housing for dairy cows has many different layouts and the space allocated for cows differs considerably. The objective of the present study was to investigate possible associations between barn layout and milk yield for different parities in small dairy freestall barns. Layouts of 204 Norwegian freestall barns constructed during the period from 1995-2005, and with a mean herd size of 42.7 ± 15.5 cows, were obtained and merged with milk yield data and calving interval, for each parity, from the Norwegian Milk Recording System (NDHRS). The milk yield dataset contained 20,221 different lactations from these 204 herds. Both simple mixed models including the different explanatory variables one by one together with parity, calving interval and herd as random effect, and a final mixed model including all significant explanatory variables, were created.

The final mixed model estimates show that only primiparous cows benefit from increased free space allocation. Milk yield was generally higher in automatic milking system (AMS) barns compared to barns with milking parlors, but not for primiparous cows. Milk yield was higher for all parities for barns using separation pens in accordance with the recommendations. Barns with two or more dead end alleys had lower milk yield compared to layouts without dead end alleys.

Primiparous cows benefit from water troughs located for easy access and respond by increased milk yield. In 10 % of the barns the water trough capacity was less than 47% of the recommendations, and all parities benefit from a water trough capacity higher than this level. Higher parities had increased milk yield when water trough capacity was more than 80 %. Feed bunk space, number of freestall rows or the location of freestalls had no significant effect on the milk yield.

The present study show that increased space and improved access to water is beneficial to primiparous cows, whereas layouts without dead end alleys and improved water capacity is beneficial for all cows in freestall systems.

Keywords: Freestall housing, layout, milk yield, parity, lactation

INTRODUCTION

Even in small dairy freestall barns, the space allowance (m^2/cow) may vary considerably (Næss and Bøe, 2010). Reducing the space will, of course, reduce the building costs (Gazzarin and Hilty, 2002), but may also influence production parameters negatively. Data from other production animals like growing-finishing pigs (NCR-89 Committee on Confinement Management of Swine, 1986; Brumm and Miller, 1996), poultry (Dozier et al., 2006), and cattle (Ingvartsen and Andersen, 1993) all show that relevant production parameters are impaired by reduced space allowance. Also for dairy heifers daily gain and feed intake decreased with decreasing resting area (Fisher et al., 1997; Mogensen et al., 1997). Data from dairy sheep (Caroprese et al., 2009) show that reducing the space also caused a reduction in milk yield. For dairy cows, the effect of limited space is less well documented. Fregonesi and Leaver (2002) did not find any effect of reduced total space in freestall systems, while Henneberg et al (1986) found reduced milk yield when reducing alley widths. Graves (1989) observed that herds with a high milk yield often seem to have larger space per cow, and Simensen et al. (2010) found that milk yield increased with increasing herd sizes in small freestall dairy barns.

Unlike the rather uniform space provided for production animals like pigs, sheep and poultry, the freestall system is divided into separate areas for lying (the freestalls), feeding, walking, and milking. Recommendations for dimensions of freestalls differ (CIGR, 1994; Bickert et al., 2000; ASABE, 2006), though freestall dimensions seem to have no effect on behavior and lying time (Tucker et al., 2004). Still, this variation in freestall dimensions has only a limited effect on the total area allocated for cows (TCA). Overstocking (> one cow per freestall), however, will certainly influence the area measured as TCA. It may also have a negative impact on the lying behavior of the cows by reducing the lying time (Friend et al., 1977; Fregonesi et al., 2007; Krawczel et al., 2008). Recommendations for alley widths differ (CIGR, 1994; Bickert et al., 2000; Graves, 2000), and alley widths do have a significant impact on the TCA. However, only one scientific study has focused on the negative effects of reduced alley width (Henneberg et al., 1986). The organization of the alleys is important to achieve optimal cow traffic and dead end alleys should be avoided (Smith et al., 2000).

Reducing feed bunk space has had a negative effect on feeding behavior (Friend et al., 1977; DeVries et al., 2004), especially for low ranked cows (Huzzey et al., 2006). In several recommendations (CIGR, 1994; McFarland, 2000), the importance of an adequate water supply is pointed out. Cows are found to prefer, and to drink more, from larger troughs (Pinheiro Machado Filho et al., 2004; Teixeira et al., 2006). However, documentation of possible negative effects on milk yield from reducing feed bunk space or amount of water supply is scarce.

The importance of separate areas for special need cows is emphasized in all recommendations (Cook and Nordlund, 2004; Kammel and Graves, 2007), but data from Norwegian herds show that these areas often are minimized, or even not present (Næss and Bøe, 2010). It is most likely that the absence of such areas will influence milk production, but no relevant data seem to exist.

Primiparous cows are found to benefit from separate grouping from older animals by increased feed intake and productivity (Krohn and Konggaard, 1979; Grant and Albright, 2001). Kjæstad and Myren (2001a; b) found that approximately one third of the heifers refused to use the freestalls for the first two weeks after being transferred to the lactating cow group. However, separating primiparous cows is not feasible in small herds.

The aim of this study is to investigate possible associations between barn layout and milk yield for different parities in small dairy freestall barns.

MATERIALS AND METHODS

The Herds

This study was part of a larger descriptive and cross-sectional project on freestall housing. Since we did not have a complete list over freestall barns in Norway, a questionnaire was sent to all dairy advisors and a list of 2,400 farms was obtained. These farmers received a questionnaire covering several aspects of their housing system. To be included in the final study, farmers had to fulfill our inclusion criteria; have a freestall barn, volunteer to participate, have a herd size > 20 standardized cow years based on the year 2005 (cow year = number of days from first calving to culling within one year, divided by 365), and have a barn built in the years 1995 to 2005. As we expect some housing systems to be common in the future, all barns with automatic milking system (AMS) (n = 44), with solid concrete floors (n = 105), or rubber solid floors (n = 24) in the alleys were included in the barns under study. Traditionally freestall barns in Norway have been constructed with slatted floors, and such buildings were only included if they were located in the same municipality as the farms mentioned above. The final database included 232 free-stalled dairy herds located all over Norway. Three herds with the Jersey breed were excluded, and 25 herds were excluded because information about floor plans was missing. The final material in this study thus included 204 herds.

Observations on Barn Layout

During the period from September 2006 to May 2007 all the barns were visited once by one of five trained observers. In the training period the individual observers registered at the same farm. The figures and observations were compared and discussed in order to harmonize the results. Farmers were asked to provide detailed drawings used during the barn-building process. Approximately 80% of the farmers were able to provide such drawings. On these farms all main dimensions of the building were measured in order to be sure that the drawings were correct. For the other buildings all relevant dimensions for the layout were measured during the field work. For more details, see Næss and Bøe (2010). The layout variables tested in the models are listed below. For further information about classes and number of cases, see Table 1.

Layout Variables

Feed bunk space:	Length of feed bunk space per freestall in the lactating cow section.
Milking system:	Milking parlor (MP) or automatic milking system (AMS).
Insulation:	Insulated or not insulated buildings.
Ventilation:	Natural ventilation (NV): With fixed inlets and open ridge. Controlled natural ventilation (CNV): Controllable inlets in the walls and outlets in the ridge. Mechanical ventilation (MV): Controllable inlets and fans.
Feed stalls:	Partitions between adjacent cows at the feed bunk (DeVries and von Keyserlingk, 2006).
Separation pens:	Pens for special needs cows (maternity cows and cows with health problems). To fulfill the criteria for inclusion in the study there should be at least one 10 m^2 pen (CIGR, 1994) per 25 cows (Bickert et al., 2000) and the pens should be in practical use.
Number of freestall rows:	Number of freestall rows in the lactating cow section.
Freestall location:	Location of freestalls in relation to the feed table (feed bunk) according to Næss and Bøe (2010): one side of feed table (OSF), in an own separate section (OS) or combinations (all other layouts, including freestalls oriented on both sides of the feed table).
Dead end alleys:	Feed alleys or freestall alleys without crossovers at the ends, and with a minimum length of 2.4 m, and a width of less than 3.0 m.
Separation of dry cows:	Dry cows in a separate group.
Water trough location:	Location of water trough in the barn (crossovers, feedline etc).
Water trough capacity:	Water trough capacity (WTC) in %. 100 % was set to be one drinking bowl per 8 cows or 10 cm accessible perimeter of a water trough per cow (CIGR, 1994). WTC was divided into five hierarchic dummy variables with 10, 25, 50, 75 and 90 % of the herds respectively.

Cow and Milk Yield Data

Milk yield data, parity and calving interval, for each individual lactation, was obtained from the Norwegian Dairy Herd Recording System (NDHRS) (Osteras et al., 2007). In Norway, milk yields are weighed monthly on the farms and reported to NDHRS. From these data a pre-estimated 305-day milk yield exists in the database. This 305-day milk yield was derived from lactations that started with a normal calving in 2005, 2006 or 2007. All lactations with less than 305 days-in-milk were deleted as well as lactations with more than 450 days–in-milk (considered to be abnormally long lactations). The final dataset was also restricted to the pure bred Norwegian Red Breed which is about 94 % of the dairy cattle population in Norway. The milk yield dataset comprised 20,221 different lactations using 12,118 different cows and 204 different herds.

Definitions of Variables Extracted from NDHRS

Milk yield	Milk yield calculated for a 305 days-in-milk lactation.
Calving interval	Number of days between two calvings.
Parity	Lactation number. Lactation four and more were merged into one group in the analysis.
Herd size	Mean number of cows in the barn (lactating and dry cows) reported as standardized cow-year (the sum of number of days from first calving to culling within one calendar year divided by 365).
Free space allocation (FSA)	Free space (in m^2) allocated per standardized cow-year, including freestalls, alleys and crossovers (Næss and Bøe, 2010).

Models and Statistical Analyses

Statistical analyses were performed using “mixed models” in SPSS 17 for Windows (SPSS, Inc., Chicago, Ill.) with 305 days milk yield for each lactation as dependent variable. The models were also run in SAS v 9.1 (Cary, NC). As independent variable in the model both parity and calving interval for that specific lactation was forced into the model as these two variables obviously have an impact on milk yield. Additionally all relevant variable from the design or the management of the free stall was introduced into the model one by one. In all models the herd identity was included as random effect to adjust for lactations within the same herd being correlated or not independent of each other.

The model building started with including one extra variable separately into the model including parity, calving interval and herd as random effect according to Dohoo et. al. (2003).

Equation 1:

$Y_i = \beta_0 + \beta_1*\text{parity}_i + \beta_2*\text{calving interval}_i + \beta_3*X_{1i} + \mu_{herd(i)} + \varepsilon_i$

Where Y_i = 305-day milk yield in kg for individual lactation, β_0 = intercept, β_1 = fixed effect of parity, β_2 = fixed effect of calving interval, β_3 = fixed effect of the included separate variable $X_{1i,}$ $\mu_{herd(i)}$ = random effect on herd level containing the i^{th} lactation, and ε_i = random effect for i^{th} lactation.

The Aikake's Information Criterion (AIC) and significance level were recorded for all these models separately. Thereafter, a final model was constructed using forward stepwise procedure by including the additional fixed effect of the variable which had the lowest and most significant AIC level from the separate models, one by one. The starting model was equation 1 including the variable which gave the lowest AIC, and including the variables one by one according to the AIC value from equation 1. For each variable the interaction between parity and the fixed effect variable was also tested in the model. All variables with a $P < 0.10$ were tested by the forward stepwise procedure. If neither the newly introduced fixed effect variable nor the interaction term with parity was significant, this variable was excluded from the model. If the fixed effect was not significant but the interaction term was significant both the fixed simple effect and the interaction term were included for further testing, including more variables. At this point the significant level was set at $P < 0.05$. The final model can thus be expressed as:

Equation 2:

$$Y_i = \beta_0 + \beta_1 * parity_i + \beta_2 * calving\ interval_i + \beta_3 * (X_{1i}) + \ldots + \beta_k * (X_{ki}) + \beta_4 * parity_i * X_{1i} + \ldots + \beta_k * parity_i * X_{ki} + \mu_{herd(i)} + \varepsilon_i$$

Where the parameters in Equation 2 have the same meaning in Equation 1 and

$\beta_3*(X_{1i}) + \ldots + \beta_k*(X_{ki})$ = fixed effect of the included variables $X_{1i} \ldots\ldots X_{ki}$

$\beta_4*parity_i*X_{1i} + \ldots + \beta_k*parity_i*X_{ki}$ = interaction between parity and relevant $X_{1i} \ldots\ldots X_{ki}$

RESULTS

The 305 days milk yield was 6,778 kg in mean with a STD of ± 1,595 kg. Minimum and maximum was 1,102 and 14,640 respectively. The results from the separate model, including the different explanatory variables one by one, together with parity, calving interval and herd as random effect are presented in Table 1, together with the corresponding *P*-values . The result from the final model including all significant fixed effect variables is presented in Table 2, together with the corresponding *P*-values.

The variables “calving interval” and “parity” were included in all simple models and were highly significant even in the final model (Table 2). Interestingly there were significant interactions between parity and “free space allocation”, “milking system”, “ventilation”, “water trough location” and “WTC < 80 % ” (Table 2).

Milk yield increased with increased herd size in the simple model; however “herd size” was excluded in the final model, as *P*-value > 0.05. Increased free space allocation tended to be associated with higher milk yield in the simple model, but in the final model the estimates show that only primiparous cows benefit from increased free space allocation (Table 2).

In general there was no significant increase in milk yield in herds with AMS. However, taking into account the interaction with parity milk yield was significant higher in AMS barns compared to barns with milking parlors. However, for primiparous cows this effect was negligible (Table 2) and not significant.

Table 1: Effect of housing conditions on milk yield. Results from simple mixed models where one fixed effect variable is adjusted for parity, calving interval and random herd effect.

(* Mean herd size: 42.7 ± 15.5 cows, range: 17.6 – 80.2, Free space allocation: 7.94 ± 1.78 m^2 per cow, range: 3.5 – 18.5, Feed bunk space: 0.56 ± 0.16 m per cow, range: 0.26 – 1.05)

Variable name	Class	n	Estimate	Std. Error	P-value
Herd size	Continuous *	20221	8.84	3.49	0.01
Free space allocation	Continuous	20221	43.86	25.90	0.09
Feed bunk space	Continuous	20221	-307.50	311.42	0.33
Milking system	AMS	3955	256.94	133.93	0.06
	Milking parlor (MP)	16266	0.00		
Insulation	Insulated	17266	154.98	151.82	0.31
	Not insulated	2955	0.00		
Ventilation	Controlled natural ventilation (CNV)	3573	347.67	189.21	0.07
	Mechanical ventilation (MV)	13245	138.41	143.18	0.34
	Natural ventilation (NV)	3403	0.00		
Feed stalls	Yes	2285	338.44	180.38	0.06
	No	17936	0.00		
Separation pens	Guidelines not fulfilled	12122	-330.74	113.87	0.004
	Missing	2443	-20.99	179.62	0.91
	Guidelines fulfilled	5656	0.00		
Number of freestall rows	1-2 rows	5721	-97.79	128.39	0.45
	3 rows	6781	148.99	123.43	0.23
	4 or more rows	7719	0.00		
Freestall location	Combinations	3894	-136.84	132.71	0.30
	In an own section (OS)	3546	-111.97	135.31	0.41
	One side of feed table (OSF)	12781	0.00		
Dead end alleys	One "dead end alley"	5233	16.04	124.54	0.90
	2 or more "dead end alleys"	4727	-323.62	123.85	0.01
	No "dead end alley"	10261	0.00		
Separation of dry cows	Yes	8081	183.82	106.32	0.09
	No	12140	0.00		
Water trough location	At the feed bunk (FB)	1894	-12.28	184.64	0.95
	In front of the first freestall row (FFR)	1912	37.85	198.20	0.85
	In crossovers (CO)	4964	-70.54	142.22	0.62
	Next to a wall (NTW)	5063	-257.86	137.49	0.06
	Combinations	6388	0.00		
Water trough capacity (WTC)	WTC < 47%	1832	-441.29	174.80	0.01
	WTC > 47%	18389	0.00		
	WTC < 60%	4916	-171.14	119.41	0.15
	WTC > 60%	15305	0.00		
	WTC < 80%	11425	-103.48	103.21	0.32
	WTC > 80%	8796	0.00		
	WTC < 104%	16448	-221.05	122.07	0.07
	WTC > 104%	3773	0.00		
	WTC < 133%	18733	-206.65	177.59	0.25
	WTC > 133%	1488	0.00		

Table 2: Estimates for milk yield for significant housing conditions in the final mixed model including 20,221 different lactations from 204 herds.

Fixed effect	Class	Mean ± SD	n	Estimate	Std. Error	*P*-value
Intercept			20,221	4076.43	374.54	0.00
Parity	Parity 1		8,171	-1935.09	167.75	0.00
	Parity 2		5,583	-886.92	175.82	0.00
	Parity 3		3,454	-369.43	193.62	0.06
	Parity 4 and up		3,013	0.00	0.00	.
Calving interval (Days)		363.0 ± 31.3	20,221	10.19	0.28	0.00
Free space allocation (FSA- m^2/cow)		7.94 ± 1.78	20,221	-8.95	30.19	0.77
Parity=1 * FSA			8,171	37.79	15.68	0.02
Parity=2 * FSA			5,583	11.61	16.34	0.48
Parity=3 * FSA			3,454	16.56	17.97	0.36
Parity=4 * FSA			3,013	0.00	0.00	.
Milking system	AMS		3,955	360.50	156.22	0.02
	Milking parlor (MP)		16,266	0.00	0.00	.
Parity 1 * AMS			1,654	-321.85	73.92	0.00
Parity 2 * AMS			1,082	-16.14	78.30	0.84
Parity 3 * AMS			650	-47.60	86.27	0.58
Parity 4 * AMS			569	0.00	0.00	.
All parities * MP			16,266	0.00	0.00	.
Ventilation	Controlled Natural Ventilation (CNV)		3,573	632.86	198.35	0.00
	Mechanical Ventilation (MV)		13,245	579.01	172.33	0.00
	Natural Ventilation (NV)		3,403	0.00	0.00	.
Parity 1 * CNV			1,406	-310.15	92.73	0.00
Parity 1 * MV			5,317	-292.20	85.69	0.00
Parity 2 * CNV			968	-249.65	97.89	0.01
Parity 2 * MV			3,677	-160.80	90.19	0.07
Parity 3 * CNV			634	-198.56	106.77	0.06
Parity 3 * MV			2,245	-103.56	98.98	0.30
Parity 4 * All classes			3,013	0.00	0.00	.
All parities * NV			3,403	0.00	0.00	.
Separation pens	Guidelines not fulfilled		12,122	-308.92	117.80	0.01
	Missing		2,443	-137.59	181.16	0.45
	Guidelines fulfilled		5,656	0.00	0.00	.
Dead end alleys	One "dead end alley"		5,233	-41.13	125.09	0.74
	2 or more "dead end alleys"		4,727	-360.25	127.05	0.01
	No "dead end alley"		10,261	0.00	0.00	.
Water trough location (WTL)	At the feed bunk (FB)		1,894	-43.76	206.28	0.83
	In front of the first freestall row (FFR)		1,912	26.27	213.43	0.90
	In crossovers (CO)		4,964	-36.92	159.02	0.82
	Next to a wall (NTW)		5,063	-45.92	156.56	0.77
	Combinations (COMB)		6,388	0.00	0.00	.
Parity 1 * FB			757	10.92	106.23	0.92

Parity 1 * FFR		760	252.26	102.29	0.01
Parity 1 * CO		2,000	-33.14	75.46	0.66
Parity 1 * NTW		2,043	-167.76	78.31	0.03
Parity 2 * FB		546	154.69	111.13	0.16
Parity 2 * FFR		543	174.97	107.43	0.10
Parity 2 * CO		1,337	99.19	79.91	0.21
Parity 2 * NTW		1,401	-95.21	82.66	0.25
Parity 3 * FB		335	98.06	121.53	0.42
Parity 3 * FFR		331	133.67	118.01	0.26
Parity 3 * CO		859	36.11	87.48	0.68
Parity 3 * NTW		851	-70.01	90.72	0.44
Parity 4 * All classes		3,013	0.00	0.00	.
All parities * COMB		6,388	0.00	0.00	.
Water trough capacity (WTC)	WTC < 47%	1,832	-325.07	183.77	0.08
	WTC > 47%	18,389	0.00	0.00	.
Water trough capacity (WTC)	WTC < 80%	11,425	-229.95	113.05	0.04
	WTC > 80%	8,796	0.00	0.00	.
Parity 1 * WTC < 80 %		4,582	200.68	54.27	0.00
Parity 2 * WTC < 80 %		3,132	137.05	57.18	0.02
Parity 3 * WTC < 80 %		1,973	107.66	62.78	0.09
Parity 4 * WTC < 80 %		1,738	0.00	0.00	.
All parities * WTC > 80 %		8,796	0.00	0.00	.
Random effects					
Herd*		204	46,8185	50,092	<0.001
Random error		20221	1467,652	14,682	<0.001

*Random effect on herd level = 24.2 %

Milk yield was significantly higher in barns with controlled natural ventilation and mechanical ventilation (insulated barns) compared to natural ventilation (typical for uninsulated barns, cold barns). The differences in milk yield were more pronounced for higher parities.

Feed bunk space had no significant effect on the milk yield. Barns with feed stalls tended to have higher milk yield. However, this effect was not found to be significant in the final model. Herds that kept dry cows together with lactating cows tended to produce less milk compared to those in barns with a separate section for dry cows, but this effect was not found to be significant in the final model either.

Both in the simple and final models, and for all parities, the milk yield was higher for barns using separation pens in accordance with the recommendations.

Number of freestall rows and the location of freestalls had no significant effect on the milk yield. Barns with two or more dead end alleys had a lower milk yield compared to layouts without dead end alleys. Layouts with one dead end alley did not differ from those with no dead end alleys in any of the models.

In the simple model location of water troughs next to the wall tended to give lower milk yield. The final model shows that only primiparous cows produced less milk in barns with water troughs located next to the wall. They also benefit from water troughs located in front of the first freestall row. For all other parities the location of water troughs had no effect on milk yield.

In 10 % of the barns the water trough capacity was less than 47% of the recommended capacity, and here the milk yield was significantly lower. Even in barns with less than 104 % of the recommended water trough capacity the milk yield tended to be lower in the simple model. According to the final model all parities benefit from a water trough capacity higher than 47% while only cows in higher parities benefit from water trough capacity higher than 80 %.

DISCUSSION

The results from the present study show that it is primiparous cows, especially, that benefit from increasing space and easy access to the barn facilities (water, feed), and respond by increased milk yield. This statement is supported by Grant and Albright (2001) who, in their review, conclude that primiparous cows benefit from being grouped separately by increased feed intake and productivity. Krohn and Konggaard (1979) quantified this increase in milk yield to be 5 – 10%. However, in small herds, primiparous cows are often kept together with lactating cows.

The generally higher milk yield in herds using AMS is supported by the conclusion in the review article of Svennersten-Sjaunja and Pettersson (2008). However, they also reported that some studies have shown similar milk yield in herds with AMS and manual milking. In the present study no increase in milk yield could be seen for primiparous cows. Looking at all animals in the herd as a whole, this might be the reason why some studies have found similar milk yield. Spolders et al. (2004) found that primiparous cows visited the milking unit more often than multiparous cows, but the increased milking frequency had no effect on milk yield. Another statement that supports our findings is that cows of low social rank, as primiparous cows often are, spend more time waiting in line in front of the milking unit (Melin et al., 2006).

Several authors have reported reduced feeding time when the feed bunk space is reduced (e.g. DeVries et al., 2004; Huzzey et al., 2006), but Olofsson (1999) observed that the cows compensated by increased consumption rate when feed bunk space was reduced. This may explain the findings of Friend et al. (1977), that the actual feed intake was not reduced until the feed bunk space was less than 0.2 m per cow. As mean linear feed bunk space was 0.59 m (min. 0.26 m) per freestall (Næss and Bøe, 2010) in the present study, even low ranked cows seem to have had sufficient access to the feed table. Hence it is not surprising that feed bunk space had no significant effect on milk yield.

The number of freestall rows will normally influence feed bunk space per freestall (Mentink and Cook, 2006). However, just as feed bunk space, the number of freestall rows had no effect on milk yield. Even though the location of freestalls in a separate section or in different combinations has been found earlier to occur more often in typical rebuilt barns (Næss and Bøe, 2010), the location of freestalls alone had no effect on milk yield.

The results of Simensen et al. (2010), showing increased milk yield with increasing herd sizes in small freestall dairy barns, may indicate an interaction between group size and space allowance. Seemingly this effect also occurred in the present study, but when adjusting for other variables, the “herd size” effect disappeared. Interestingly, Petherick et al. (1983) point out that the need for space is greater in small groups, and the same principle is actually laid down in the European regulations for dry sows (EEC, 2001), where the unobstructed floor area must be increased by 10% for groups of fewer than six pigs. Still, there seems to be no scientific evidence to support this requirement in relation to pigs (Turner et al., 2003). Nevertheless, Morrison et al. (1981) found groups of five cattle to have less daily feed intake than a group of ten cattle with the same space allocated per animal.

In the present study, one dead end alley had no effect on the milk yield whereas two or more dead end alleys resulted in decreased yield for all parities. Cows seem to cope with one dead end alley, probably because of the possibility of avoiding these areas in the barn. This supports recommendations that say that layouts with dead end alleys should be avoided (Bickert et al., 2000; Smith et al., 2000).

The need for adequate space for cows with special needs is emphasized by several authors (Cook and Nordlund, 2004; Kammel and Graves, 2007). In the present study there was insufficient space for special needs cows, and many farmers reported that they did not make use of these pens either. The present study indicates that this is not good practice.

The present study shows that primiparous cows benefit from water troughs located for easy access on the first freestall row. This supports the findings of Brouk et al. (2003) that water should be located for easy access and abundant availability, and those of Bickert et al. (2000) that more space and more locations should be provided when primiparous cows are housed with older cows. Water trough capacity below 47 % of the recommended capacity was in general associated with lower milk yield. For water trough capacity below 80 %, milk yield decreased with increasing parity number. Sufficient water supply is essential in the lactating period (McFarland, 2000). Higher parities produce more milk, and seem to be more sensitive to water access.

Lower milk yield in cold buildings with natural ventilation was unexpected. High yielding dairy cows have low LCT (Lower Critical Temperature) (Young, 1981) and comparable production results in insulated and cold buildings have earlier been found (Zähner et al., 2004). Therefor it is reasonable to assume that the result in the present study is influenced by other factors like management routines, simple feeding systems etc. on these farms.

CONCLUSIONS

In general, free space allocation has a limited effect on milk yield, but primiparous cows seem to benefit from increased space in small freestall herds. Layouts with two or more dead end alleys are negative for milk yield whereas feed bunk space, within the range of existing recommendations, does not affect productivity. Use of separation pens for special needs cows has a positive effect on milk yield. Milk yield is higher in herds with AMS, except for primiparous cows. Easy access to water troughs is important for primiparous cows while sufficient water trough capacity seem to be essential for multiparous cows.

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I was gratified to be able to answer promptly. I said I don't know.

Mark Twain

Dairy barn layout and construction: Effects on initial building costs

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ABSTRACT

On small dairy farms high investment costs may delay the modernizing of facilities. The aim of this study was to investigate the importance of economics of scale in building costs of barns compared to other sources of variation in costs. The study includes 44 farms with a mean herd size of 49.5 ± 15.1 cows, built between year 1999 and 2006 and with a mean total area in the barns of 896 ± 454 m^2. Building cost data were obtained from farmers and merged with construction, mechanization and layout data from the same barns.

Plot of the data reveals that construction costs decreased up to approximately 1250 m^2 while mechanization costs and total building costs decreased up to approximately 1000 m^2. A further increase in building area had only limited effect on the building costs per m^2. Models including explanatory variables showed that milking- and service area was significantly more expensive than other areas. AMS-barns were all together not significantly more expensive than other barns, since the increased mechanization cost is offset by need for less milking area. Farmers remodelling their barns were able to realise a modernized building for a certain herd size for a lower cost compared to a completely new building. The value of own effort varied considerably between projects, and in many cases farmers will be able to find alternative income sources with a higher hourly rate than the model predicts.

Keywords: Dairy cows, cubicle housing, layout, building costs

1. INTRODUCTION

On small dairy farms, especially in cold climate regions, high investment costs and lack of investment capital may delay the modernizing of facilities (O'Donoghue et al., 1998; Lazarus et al., 2003). Even though Tauer (2001), based on simulations of “best practice”, found that many small farms had high production costs due to inefficiency, newer buildings tend to be more efficient (Stahl et al., 1999). Moreover, larger buildings have lower investment costs per cow (Hoglund and Albright, 1970; Gjerde, 1996; Gazzarin and Hilty, 2002).

Researchers have been searching for low cost barns for many years (Achilles et al., 1974; Gartung et al., 1983), and find that building layout and construction affect building costs (Pereira et al., 2003; Fernández et al., 2008). Barns including posts might be cheaper than completely open rooms (Simon et al., 2007), and make stepwise building possible (Bjerg and Fog, 1985). Domestic regulations, material costs, labour prices and building tradition might also influence on building costs (Van Caenegem, 2003).

Uninsulated or open barns are shown to be sufficient to avoid high-yielding dairy cows from overtaxing the thermoregulatory ability in cold climate (Arave et al., 1994; Zähner et al., 2004). Berg (1995) found that the potential for reducing building costs by building uninsulated dairy barns was scarce. However, more open buildings (Simon et al., 2007) and also more simple interior (Dolby and Ekelund, 1994) may reduce the building costs considerably.

An extensive use of own work in the building process might reduce the cash expenditure (Van Caenegem et al., 2004), but may also negatively affect the milk production during the building period (Aschan and Stockzelius, 1997).

Pereira et al. (2005) found the costs of slatted floors to be up to 40% higher than floors built for tractor scrapers, and Gartung and Krentler (1987) found the lowest costs manure handling and storage system to be 50% of the most expensive alternative. However, mechanization and handling systems affect working conditions and animal welfare in addition to building costs. The mechanization of milking, for example, is not only a question of minimizing costs (e.g. Wagner et al., 2001; Hyde and Engel, 2002). The introduction of the AMS (robotic milking) during the last decade also has socio-economic effects (Wauters and Mathijs, 2004) by e.g. giving a more flexible solution with respect to working hours and effects on the cows by changed daily time budgets (Svennersten-Sjaunja and Pettersson, 2008).

An alternative to build new separate buildings is to remodel and expand present buildings. Remodelled facilities may require lower investments, but may also have poorer functionality compared to new buildings (Ekelund and Dolby, 1993; Bewley et al., 2001). Remodelling or a more gradual expansion may also offer attractive returns compared to more capital-intensive investments in new facilities (Lazarus et al., 2003).

As mentioned above there are economics of scale in construction costs of barns. Comprehensive variations in space allocation in dairy cubicle barns have earlier been found (Næss and Bøe, 2010). A well organized layout may improve animal welfare. However, allocating more space for cows may also make it easier to achieve a good layout (e.g. width of alleys: Henneberg et al., 1986). Thus, the building costs is also an important factor for indentifying the investment costs associated with improvements of animal welfare in new buildings. The aim of this study is to investigate the importance of scale compared to other sources of variation in building costs.

2. MATERIALS AND METHODS

2.1 STUDY FARMS

The present study includes 44 farms of a larger descriptive and cross-sectional project on cubicle housing of 232 farms all over Norway (Simensen et al., 2010). Our inclusion criteria in the present study were: volunteer to participate, able to obtain building cost information and clear delimitation of work included in the building project. Mean herd size including milking- and dry cows was 49.5 ± 15.1 cows, ranging from 22 to 80 cows, and the barns were built between year 1999 and 2006. Mean total area in the barns was 896 ± 454 m^2 and ranged from 235 to 1997 m^2. Remodelled buildings included many different layouts, and most of these buildings had a new section in connection with a remodelled part. Table 1 shows the number of barns with different housing conditions in the selection.

Table 1 - Conditions related to building type and construction in the present study.

Variable	Class	Number of herds (n=44)	% of herds (n=44)
Building type	New building	29	66
	Remodelled	15	34
Insulation	Insulated	36	82
	Uninsulated	8	18
Ventilation	Mechanical	25	57
	Natural	11	25
	Natural controlled	8	18
Milking system	AMS	10	23
	Milking parlour	34	77
Floor construction	Solid floor and scrapers	26	59
	Slatted floor	18	41
Roof construction	Open	35	80
	With posts	9	20
Main construction material	Steel	18	41
	Wood / laminated wood	26	59
Service rooms on first floor	No	31	70
	Yes	13	30

As a part of the main project all herds were visited once by trained observers during the period from September 2006 until February 2008. Based on the drawings, measurements by the observers, and pictures, the space allocation was calculated for each barn. Different area categories was defined according to their function and expected construction costs (Table 2). For more information about the layout see (Næss and Bøe, 2010).

Table 2 - Definition of different kind of areas in the building

Area	Definition
Cow area	Cubicles, alleys and crossovers for milking- and dry cows, space for special needs cows and holding area for milking.
Milking area	Milking parlour, return alley and milking room.
Replacement area	Space for calves, heifers and bulls.
Feeding area	Feeding table, driveway and feed mixing room.
"Man area"	Walkways in the barn.
Service rooms	Dressing room, office and technical rooms.
Total area	The sum of all areas in the barn

The surface area of the superstructure (roof and walls) was computed. Divided by the total area it is denoted “geometry”. Another source of variation between costs of building projects may be the variation in manure storage capacity. Thus “manure storage” was calculated as volume of the containers (m^3) and expressed as m^3 storage per m^2 total area. Farms located in the Norwegian counties of Rogaland and Trøndelag were identified with the dummy variable “husbandry regions”. These are regions with higher density of dairy farms and hence a higher number of competent contractors.

2.2 BUILDING COST DATA

Farmers were asked to provide abstract of the accounts for building costs divided on construction and mechanization costs. Construction costs per m^2 (COC) represented the “building shell” including floor, walls and roof, mechanization costs per m^2 (MEC) represented interior and machinery, and total building costs per m^2 (TBC) was the sum of COC and MEC. The value of own effort was not included in the reported building costs. Instead time sheets or estimates of own effort (hours of labour input) during the construction period was obtained. A minimum of 300 hours own work was set to concern administration of the building project. All prices in Norwegian currency (NOK) were transformed to Euro (€) according to mean exchange rates (Norges Bank, 2010), adjusted by a construction cost index (Statistics Norway, 2010) and reported as 2006-prices.

Footnote: Mean exchange rate for Norwegian kroner (NOK) against Euro (€) in 2006 was 8.05 (NorgesBank, 2010).

2.3 MODELS AND STATISTICAL ANALYSIS

The plots in Fig. 2-4 suggest that for modelling average costs for both COC and TBC, we need a functional form that may provide a more or less L-shaped average cost function with respect to size. A simple model, with total cost for the building project as a linear function of total area with a fixed factor independent of size, will result in an average cost curve as a function of one divided by total area ($1/m^2$). However, we also allow this “fixed” term to be a function of the area of superstructure per m^2. This factor “geometry” declined by increased total area and “geometry” and “total area” were strongly correlated (r= -0.697, $p < 0.001$). A new variable “GeoArea” which is defined below was created for the modelling of the declining average cost:

$$\text{GeoArea (GEA)} = 1000\frac{\text{Geometry}}{\text{Total Area}}.$$

Mean GEA was 2.27 ± 2.20 per m^2 and decreased with increasing herd size as shown in Fig.1.

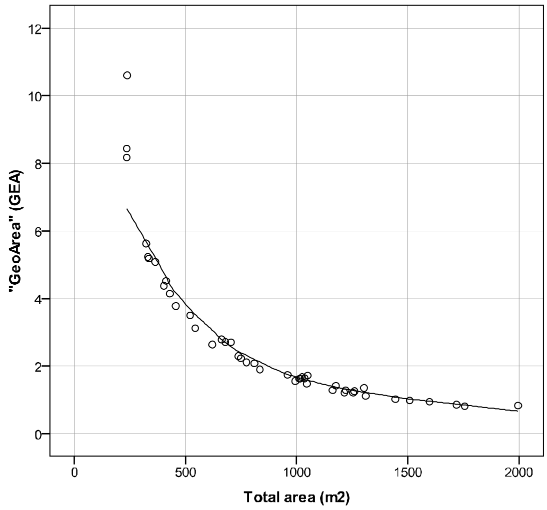

Fig. 1 - “GeoArea” (GEA) as a function of the total area.

Building costs also depend on the type of area. For example, the cost per m^2 of the milking area is substantially higher than the ordinary cow stall area. Such variations are captured by using the share of the area with the various types of rooms as explanatory variables. Other sources of variation between farms where also accounted for as the amount of own effort and volume of manure storage between building projects.

Initially, all variables were tested for correlation, and one of two class variables was excluded if Pearson $r > \pm 0.5$. In accordance with this, the variable “ventilation” was excluded due to correlation with “insulation” (r = -0.734), and “main construction material” due to correlation with “husbandry regions”(r = 0.581).

Statistical analyses were performed using General Linear Model in SPSS 17 for Windows, 2009. The Pearson correlation coefficient was used for testing the correlation between variables before including them in the models, and the Mann-Whitney U test was used comparing milking systems. The estimated models with dependent variable Y_i had the following form:

$$Y_i = \beta_0 + \beta_1 \, GeoArea_i + \sum_j \beta_j d_{ij} + \sum_k \beta_k z_{ik} + e_i$$

Where GeoArea is a nonlinear function of size as defined above, d_j refers to dummy variables, z_k refers to values which are measured as amount of square meter of the total area, and e_i is the random error.

Variables that were not relevant for the specific model were excluded from the actual analyses (COC, MEC and TBC). Variables with P-values > 0.2 in the models were excluded by "backward elimination". Which variables that were tested and included in the specific models are summed up in Table 3.

Table 3 - Variables included in the specific models

E: Excluded from the beginning due to strong correlation to other variables
N: Not relevant for the specific model
I: Included in the initial analysis and excluded later due to low significance
F: Included in the final model

Variable name	Construction costs	Mechanization costs	Total building costs
Building type	I	F	F
Insulation	I	N	I
Ventilation	E	E	E
Milking system	N	F	F
Floor construction	I	I	I
Roof construction	I	N	I
Main construction material	E	E	E
Service rooms on first floor	I	N	I
Milking area / m^2	F	I	F
Feeding area / m^2	I	I	I
"Man area" / m^2	I	I	I
Service rooms / m^2	F	I	F
"GeoArea"	F	F	F
Manure storage (m^3/ m^2)	F	N	F
Husbandry regions	F	I	F
Own effort (h / m^2)	F	I	F

3. Results and discussion

3.1 Observed building costs

The plots of COC and MEC as functions of total area suggests that the costs per m^2 were reduced by increased area up to approximately 1250 m^2 and 1000 m^2 respectively (Fig. 2 and 3). However there were comprehensive variations in both COC and MEC between farms of similarly size (Fig. 2 and 3).

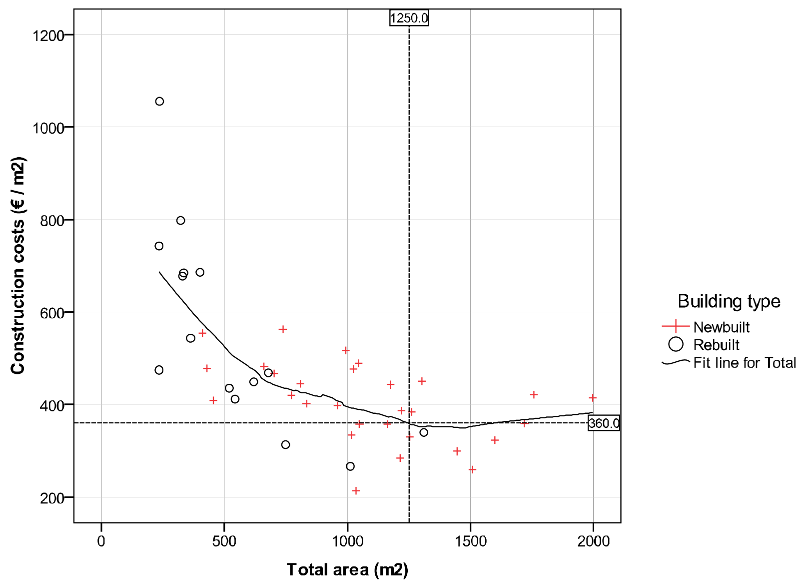

Fig. 2 - Construction costs (COC) as a function of total area (€/m^2)

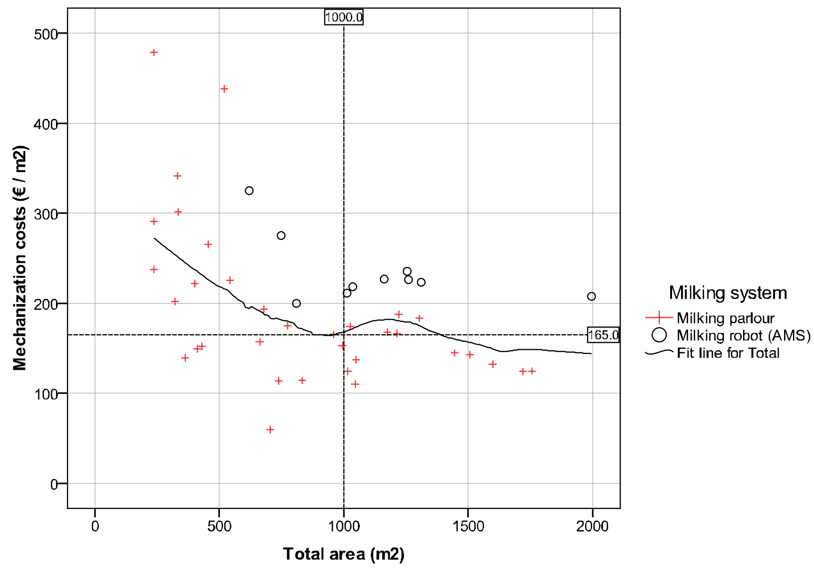

Fig. 3 - Mechanization costs (MEC) as a function of total area (€/m^2)

The variation in mechanization level was most pronounced among remodelled barns, and comparing new buildings (n=29) we found that the total area had no effect on the mechanization costs per m^2 (r = 0.02). However, the range was large (59.4 - 265.0 € / m^2) so the mechanization level varied significantly also among new buildings. Some of this variation was due to AMS as shown in Fig. 3. Small farms had often quite high mechanization level in the new section which often included the milking system and cubicles. Thus, the large share of milking area in relation to the total area is a factor that explains some of the variant in cost between smaller building projects. However, the general trend seems to be that farms with larger herds substitute labour for capital input, since farms with lager herds seem to have a higher degree of mechanization compared to buildings for smaller herds. Also TBC decreased rapidly up to approximately 1000 m^2 as shown in Fig. 4.

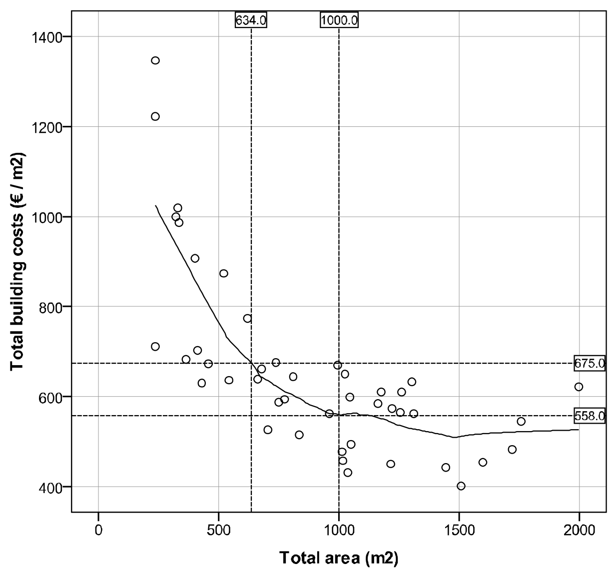

Fig. 4 - Total building costs (TBC) as a function of total area (€/m2)

Mean space allocation was 18.1 ± 8.2 m^2 per cow or 896.6 ± 454.3 m^2 for a mean sized barn (49.5 cows). 1000m^2 represents in average space for 55.2 cows. Hoglund and Albright (1970) reported lowest costs for cubicle barns for 60 or more cows which is about the same as we found many years later. Gazzarin and Hilty (2002) calculated savings equivalent to 1 % for each extra cow in the range from 35 to 55 cows while the reduction was smaller for larger barns. The present study showed the same effect with a decrease in TBC on 1.05 % for each extra cow in the corresponding range from 35 to 55 cows (634 to 1000 m^2) (Fig. 4). TBC was much higher for some of the smallest barns. Some of these barns had a high amount of relative expensive areas like milking area and service rooms.

None of the variables concerning building construction were significant factors in explaining the variation in costs per m^2 of the building projects. Uninsulated buildings were expected to be only slightly less expensive according to Berg (1995) and Sällvik (2003). In the present study there was no significant difference in TBC between insulated and not insulated buildings. There was just one uninsulated, remodelled building. However, comparing new buildings (n=29) there was no difference in TBC between these groups. In the present study the uninsulated buildings were very much alike insulated buildings. Often they had quite expensive controlled natural ventilation, and in sum they did not have significantly lower costs. More open buildings might be less expensive as Simon et al. (2007) have stated. Main construction material was neither not a significant explanatory variable. However, uninsulated buildings with steel construction tended to be less expensive.

In addition to the TBC reported in Fig. 4, the mean own effort in the building projects was 3.65 ± 2.90 hours / m^2 and ranged from 0.15 – 10.96. The amount of own effort per m^2 seemed to be higher for remodelled barns (4.19 ± 3.42 hours / m^2) compared to new barns (3.37 ± 2.62 hours / m^2) but this effect was not significant.

3.2 MODEL RESULTS

Models including the explanatory variables and parameter estimates for COC, MEC and TBC are shown in Table 4. Adjusted R^2 for COC, MEC and TBC were 0.788, 0.463 and 0.804 respectively.

Table 4 - Parameter estimates, standard error and significance level of the parameter estimates for average construction costs (COC), mechanization costs (MEC), and total building costs (TBC) (€ / m^2).

		COC		MEC		TBC	
Variable	**Class**	**Estimate: β (SE)**	**P-value**	**Estimate: β (SE)**	**P-value**	**Estimate: β (SE)**	**P-value**
Intercept		244.5 (32.7)	< 0.001	127.0 (17.7)	< 0.001	338.3 (50.2)	< 0.001
”GeoArea”	Continuous	44.7 (6.1)	< 0.001	13.3 (5.9)	< 0.030	48.5 (10.0)	< 0.001
Building type	Remodelled			68.9 (26.1)	0.012	104.2 (40.1)	
	New building			0.0 (-)		0.0 (-)	-
Husbandry regions	Yes	-55.9 (24.4)	0.027			-64.7 (30.5)	0.041
	No	0.0 (-)				0.0 (-)	
Milking area / m2	Continuous	726.7 (271.6)	0.011			1255.9 (390.0)	0.003
Service area / m2	Continuous	1199.6 (345.0)	0.001			1094.4 (433.3)	0.016
Milking system	AMS			59.0 (24.3)	0.020	81.2 (41.9)	
	Milking parlour			0.0 (-)		0.0 (-)	-
Manure storage (m3 /m2)	Continuous	29.5 (9.7)	0.004			31.3 (12.3)	0.016
Own effort (h / m2)	Continuous	-10.5 (5.0)	0.043			-8.9 (6.2)	0.163

According to the models in Table 4 an increase of one unit in “GeoArea” (GEA) represented an increase in COC of 44.7 € / m^2. The GEA had only a minor effect on the MEC (13.3 € / m^2) and the parameter estimate for TBC was of 48.5 € / m^2, not much higher than for COC. Smaller buildings have a larger building shell in relation to the total floor area compared to larger buildings, and this factor may help explain the comprehensive variation in average cost due to change in size. This effect can be illustrated by two examples:

Example 1: Keeping the size and shape of the floor constant on 25 x 40 m (1000 m^2), increasing the height of walls from 3.0 to 5.0 m and the roof angle from 20 to 30 degrees, the GEA increased with 0.36. This represented 17.1 € / m^2 or 3.1 % of TBC.

Example 2: Keeping the wall height and roof angle constant on 4 m and 25 degrees, increasing the area from 800 to 1200 m^2 (20 x 40 m to 25 x 48 m), the GEA decreased with 0.87. This represented 41.3 € / m^2 or 7.4 % of mean TBC (1000 m^2).

MEC and TBC were significant lower for new buildings compared to remodelled buildings while COC was quite similar between the two groups. However, looking at TBC, there was no difference between the groups when comparing TBC per “cow unit” (Table 5). A “cow-unit” expressed the theoretical capacity for cows in the building, where space for replacement animals were converted into space for cows using the mean space allocated for milking cows.

Table 5 - Building costs for new and remodelled buildings (mean ± SD)

			Costs € / m^2			Costs € / cow unit		
	n	**Mean m^2**	**COC**	**MEC**	**TBC**	**COC**	**MEC**	**TBC**
New	29	1088 ± 397	404 ± 85	163 ± 45	567 ± 85	5139 ± 151 0	2085 ± 537	7224 ± 1649
Remodelled	15	526 ± 310	556 ± 214	274 ± 92	830 ± 250	4762 ± 19 88	2428 ± 1010	7190 ± 2689

COC: Construction costs per m^2, MEC: Mechanization costs per m^2, TBC: Total building costs per m^2

Farmers including existing rooms in the building project were able to realise a modernized building of a certain size for a lower cost compared to a completely new building. However, according to Bewley et al. (2001) and Ekelund and Dolby (1993), they must expect lower functionality compared to new buildings.

The share of the area used as milking area and service rooms varied among the farms, and were the only areas that significantly differed from the mean in COC and TBC. For MEC there was no difference. Mean milking area as part of the total area was 8.8 ± 4.9 %. Milking areas included a complex construction, often with a surface of tiles, and were expensive. Mean service room area as part of the total area was 4.0 ± 3.5 % and had a significant effect on both COC and TBC. In 13 barns there was office or other service rooms on first floor. We expected rooms on first floor to be less expensive to construct since the building shell already was there, and the results showed no significant difference in COC or TBC between barns with and without rooms on first floor.

According to Table 4, AMS and increased milking area / m^2 contributed to a higher MEC and TBC. Among new buildings (n=29), buildings with AMS (n=6) had less COC ($p = 0.005$) and higher MEC ($p = 0.007$) compared to buildings with milking parlour (n=23). TBC was not significantly different between these groups ($p > 0.2$). Mean COC and MEC in barns with milking parlour (1045 ± 393 m^2) was 416.1 ± 82.9 € / m^2 and 148.7 ± 38.6 € / m^2 respectively. Similar for barns with AMS (1253 ± 401 m^2) the figures were 357.4 ± 81.3 € / m^2 and 218.9 ± 13.3 € / m^2. Even though AMS is expensive to install, the savings in milking area seem to compensate for almost all the extra initial costs. It has earlier been stated that barns with AMS allocated approximately 1 m^2 less space per cow for milking area compared to barns with milking parlour (Næss and Bøe, 2010). It should also be taken into account that economic life time is shorter for machinery compared to constructions, and maintenance requirements for AMS systems is expected to be higher compared to milking parlours because the level of technology is higher (Svennersten-Sjaunja and Pettersson, 2008).

The models suggest that COC and therefore also TBC were lower in husbandry regions compared to the rest of the country. Within husbandry regions, and also within other regions, COC and TBC were quite similar. A small number of farms in the north had higher TBC than in other regions outside husbandry regions. Cost competitiveness and competence might be the reason for this variation. The MEC did not differ between different parts of the country. Farm equipment companies operate all over the country and the prices seem to be more or less the same in different regions.

The amount of manure storage influenced on COC and TBC. Mean manure storage among barns including such storage (n=30) was 1.57 ± 1.15 m^3/m^2 and decreased by increasing total area ($r = -0.495$, $p = 0.005$). The large SD is explained by the fact that many barns just had a short term storage included in the building project while others had quite big storages to take care of manure from adjacent rooms.

The value of own effort in the TBC model was 8.88 € / h. This is about 50 % of the actual salary scale for farm work in Norway (NILF, 2007). In the COC model it was slightly higher

(9.04 € / h) while it in the MEC model was not significant. Even though these figures are uncertain, and suitable alternative jobs not always are available, they call attention to how farmers should prioritize their own work during the building process. Aschan and Stockzelius (1997) demonstrated that many farmers experienced reduced milk yield during the building process. Great involvement in the building process might be unprofitable if the production is suffering. However, a careful planning of the project reduced costs compared to projects with shorter planning period (Aschan and Stockzelius, 1997), and made it clearer which part of the building process that gave the best possibilities for reducing building costs by increasing the own effort (Van Caenegem et al., 2004). Cooperating farms might have more available labour resources for own effort, and in the present study many of the cooperating farms had a high amount of own effort in the building process.

4. CONCLUSIONS

The total building costs per m^2 (TBC) decreased up to approximately 1000 m^2 which in average represents a barn for 55 cows. Milking- and service area was significantly more expensive than other areas. AMS-barns were all together not significantly more expensive than other barns to build, since the increased mechanization cost is offset by less need for milking area. Remodelled barns were in general smaller and the TBC was higher than for new barns. However, farmers remodelling their barns were able to realise a modernized building for a certain herd size for a lower cost compared to a completely new building. A comprehensive variation of TBC between barns of similarly size, not explained by building conditions examined in this study, indicate that management during the construction period also is important for the TBC.

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Paper IV

Plans are only good intentions unless they immediately degenerate into hard work.

Peter Drucker

Labour input in small cubicle dairy barns with different layouts and mechanization levels.

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Abstract

When investing in new, or remodelling existing facilities for dairy cows, the functionality of the facilities, and the labour input required must be considered in addition to the initial building costs. The aim of this study was to investigate the labour input required for dairy work in different herd sizes, layouts and mechanization levels in small dairy cubicle barns. Layouts from 201 cubicle-stalled dairy herds with a mean herd size of 38.0 ± 14.5 (range 17.6 – 80.2) cows located all over Norway were obtained. The data was merged with data for the daily labour input required for the winter season. Using General Linear Model (GLM) in SPSS, we created both simple statistical models including the different explanatory variables one by one together with herd size, and a final model including all significant explanatory variables. The required labour input per cow decreased by increased herd size, up to approximately 60 cows. Barns with AMS had the same estimated labour input per cow independent of herd size. For herds with milking parlours the estimated need of labour decreased by increasing herd size from 20 to 80 cows. The estimate of required labour input was higher for rebuilt barns up to a herd size of 39 cows. The comprehensive variation in labour input indicates that optimizing building layout, developing good management routines and proper mechanization levels, would considerably reduce the required amount of labour.

Keywords: Cubicle housing, layout, labour input

1 Introduction

Many studies have focused on initial building costs in dairy housing (Gartung et al., 1983; Gazzarin and Hilty, 2002; Pereira et al., 2003) and economies of scale have been stated. Even in small dairy cubicle barns, the space allowance (m^2/cow) may vary considerably (Næss and Bøe, 2010) and thus affect the initial building costs. However, a proper barn layout may reduce the required labour input without high costs. An increased mechanization level will also reduce the required labour input and probably increase the profit levels, yet often to a higher cost (Hoglund and Albright, 1970; Karszes, 2000). Even though farmers seem to have a strong preference to maintain dairy production, specially on family farms where most of the work is done by the family themselves, a minimum income is necessary to keep them in business (Lips and Gazzarin, 2008).

The daily dairy work can be divided into milking, feeding, cleaning and other work / management (Hedlund, 2008). Total required labour input per cow varies considerably but seems to constitute about 30-50 hours per cow per year for a 80-100 cow herd, and decreases by increasing herd size (Auernhammer, 1990; Hedlund, 2008). The required labour input per cow has gradually been reduced the last 50 years (Hedlund, 2008), as illustrated by Nygaard (1977) who in the 1960’s found the labour input to be 63 hours per cow-unit and year in small tie-stall barns.

Simulations of efficiency on dairy farms based on “best practice” have shown that many small farms had high production costs due to inefficient facilities or working routines (Tauer, 2001). Larger farms are early adopters of technology and benefit more from labour-saving technologies (O’Brien et al., 2007). Bewley et al. (2001b) reported that farmers who built completely new facilities observed higher production and greater labour efficiency compared to farmers who modified their existing facilities.

Traditional milking is the most time-consuming part of the work and constitutes about 50 – 70 % of the work in cubicle housing (Hoglund, 1973; Auernhammer, 1990; Hedlund, 2008).

With AMS the required labour input is expected to be significantly lower (Schön, 2000; Hedlund, 2008), and influences the time schedule for the farmer as well (Wauters and Mathijs, 2004). Automatic feeding systems and manure scrapers are technical innovations that are expected to reduce the required labour input. This is illustrated by a reduction in required labour input for feeding from 30% in the 1960's (Nygaard, 1977) to 13 % in the 2000's (Hedlund, 2008). A properly designed section for special needs cows will also simplify the work with maternity cows and cows with health problems (Kammel and Graves, 2007). Finally farmers' attitude towards animals may influence the human-animal interaction and the time spent for animal care (Kielland et al., 2010).

The aim of this study is to investigate the required labour input for dairy work under different herd sizes, layouts and mechanization levels in small dairy cubicle barns.

2 Materials and methods

2.1 The herds

This study was part of a larger descriptive and cross-sectional project on cubicle housing. From a questionnaire sent to all dairy advisers in Norway, we obtained a list of 2,400 cubicle-housed herds in Norway. These farmers received a questionnaire covering several aspects of their cubicle housing system. To be included in the final study, farmers had to meet our inclusion criteria; volunteer to participate, have a herd size > 20 standardized cow years based on the year 2005 (cow year = number of days from first calving to culling within one year, divided by 365), and have a barn built in the years 1995 to 2005. As we expect some housing systems to be common in the future, all barns with AMS (n = 44), with solid concrete floors (n = 105) or rubber solid floors (n = 24) in the alleys were included in the study barns. Traditionally cubicle barns in Norway have been constructed with slatted floors and such buildings were only included if they were located in the same municipality as farms that met the criteria mentioned above. The final database included 201 free-stalled dairy herds located all over Norway.

2.2 Herd size and milk yield

The number of cows (herd size) on each farm was extracted from the Norwegian Dairy Herd Recording System (NDHRS) for the year of visit. Mean number of cows in the barn (lactating and dry cows) was reported as standardized cow-year (the sum of number of days from first calving to culling within one calendar year divided by 365). Mean herd size for the whole dataset (n = 201) was 38.0 ± 14.5 cows (range 17.6 – 80.2). For new buildings (n = 92) it was 41.8 ± 15.3 cows and for remodelled buildings (n = 109) it was 34.8 ± 13.1 cows.

Mean milk yield on each farm was also extracted from NDHRS. In the analysis milk yield is reported in 1000 litre per milking cow.

2.3 Observations regarding barn layout

During the period of September 2006-May 2007, all the barns were visited once by trained observers. Farmers were asked to provide detailed drawings used during the barn-building process. Approximately 80% of the farmers were able to provide such drawings. On these farms all main dimensions of the building were measured in order to assure that the drawings were correct. For the rest of the buildings all relevant dimensions for the layout were measured during the visit. For more details see (Næss and Bøe, 2010). Layout variables tested in the statistical models are listed below. For further information about classes and number of cases see Table 1.

Replacement:	Replacement area per cow (m^2/cow)
Building type:	New vs. remodelled facilities.
Building form:	Number of wings on the barn.
Milking system:	Milking parlour or automatic milking system (AMS).
Alley floor type:	Solid or slatted flooring
Number of cubicle rows:	Number of cubicle rows in the lactating cow section.
Cubicle location:	Location of cubicles in relation to the feed table according to Næss and Bøe (2010). One side of feed table, in an own section or combinations (all other layouts, including cubicles oriented on both sides of the feed table).
Separation of dry cows:	Dry cows in a separate group.
Separation pens:	Separation pens available near the pen for lactating cows.
Roughage feeding:	Method for roughage feeding. Manual handling, feeder, tractor with feeder/ feeder mixer wagon, or other handling methods.
Roughage store:	Method for storing roughage. Round bales, tower silo, horizontal silo, and other storing methods.

2.4 Labour input data

The farms included in the study were typical family farms or cooperation of 2 - 5 families, where the owners did the main part of the work themselves. The dairy work during the winter period is normally characterized by standard procedures. During the visit, the farmers were all asked to estimate regular daily input of working hours (in number of minutes per day) throughout a normal day during the indoor feeding period with all animals in the barn (no grazing animals). Time used for building and technical maintenance was not included.

Finally the labour input was merged with herd size data and calculated as minutes per standardized cow year per day.

2.5 Cleanliness score

On each farm, 10 cows were randomly selected among all lactating cows and scored for cleanliness on both sides of udder, belly, leg and thigh in addition to the rear part using a four-grade scale: 1) clean, 2) some dirt, 3) dirty, or 4) very dirty with caked-on dirt. A total cleanliness score for each cow was then calculated as the sum of scores for each body part. Finally, a mean score for every herd was calculated. For further information see Ruud et al. (2010).

2.6 Farmer's attitude

As a part of the main project an own survey regarding farmers' empathy and attitude toward animals was carried out (see Kielland et al., 2010). One part of that survey assessed farmers' attitudes towards animals in pain. On the basis of the answers, the farmers were categorized into two groups according to their agreement or disagreement with the attitude statement: "animals experience physical pain as humans do."

2.7 Models and statistical analyses

Statistical analyses were performed using "General Linear Model" in SPSS 17 for Windows (Chicago, Ill.: SPSS, Inc). Pearson correlation coefficient was used for testing the correlation between herd size and labour input. The required labour input was expected to differ between different herd sizes (Fig. 1). Hence, the model building started with including one extra variable separately into the model including "herd size".

Equation 1:

$Y_i = \beta_0 + \beta_1 * \text{Ln(herd size)}_i + \beta_2 * X_{1i} + \varepsilon_i$

Where Y_i = labour input (min / cow *day), β_0 = intercept, β_1 = fixed effect of Ln(herd size), β_2 = fixed effect of the included separate variable X_{1i}, and ε_i = random error.

Finally, a model including all variables that contributed to a higher adjusted R square for the separate models ($p < 0.1$) was created by backward elimination. If the interaction term between the variable and Ln (milk yield) was significant ($p < 0.05$), both the variable and the interaction term were tested in the final model. The final model can thus be expressed as:

Equation 2:

$Y_i = \beta_0 + \beta_1 * \text{Ln(herd size)}_i + \beta_2 * X_{1i} + \ldots + \beta_k * (X_{ki})) + \beta_3 * \text{Ln(herd size)}_i * X_{1i} + \ldots + \beta_k * \text{Ln(herd size)}_i * X_{ki} + \varepsilon_i$

Where the parameters in Equation 1 have the same meaning in Equation 2 and

$\beta_2 * (X_{1i}) + \ldots + \beta_k * (X_{ki})$ = fixed effect of the included variables $X_{1i} \ldots\ldots X_{ki}$

$\beta_3 * \text{Ln(herd size)}_i * X_{1i} + \ldots + \beta_k * \text{Ln(herd size)}_i * X_{ki}$ = interaction between Ln(herd size) and relevant $X_{1i} \ldots\ldots X_{ki}$

3 Results

Mean labour input was 11.1 ± 5.1 (min / cow *day) and ranged from 1.40 to 33.9 (min / cow*day) (Fig. 1). The labour input varied considerably between the herds, especially in small herds, and decreased by increasing herd size (r = -0.59, $p < 0.001$). The required labour seems to decrease especially up to a herd size of approximately 60 cows.

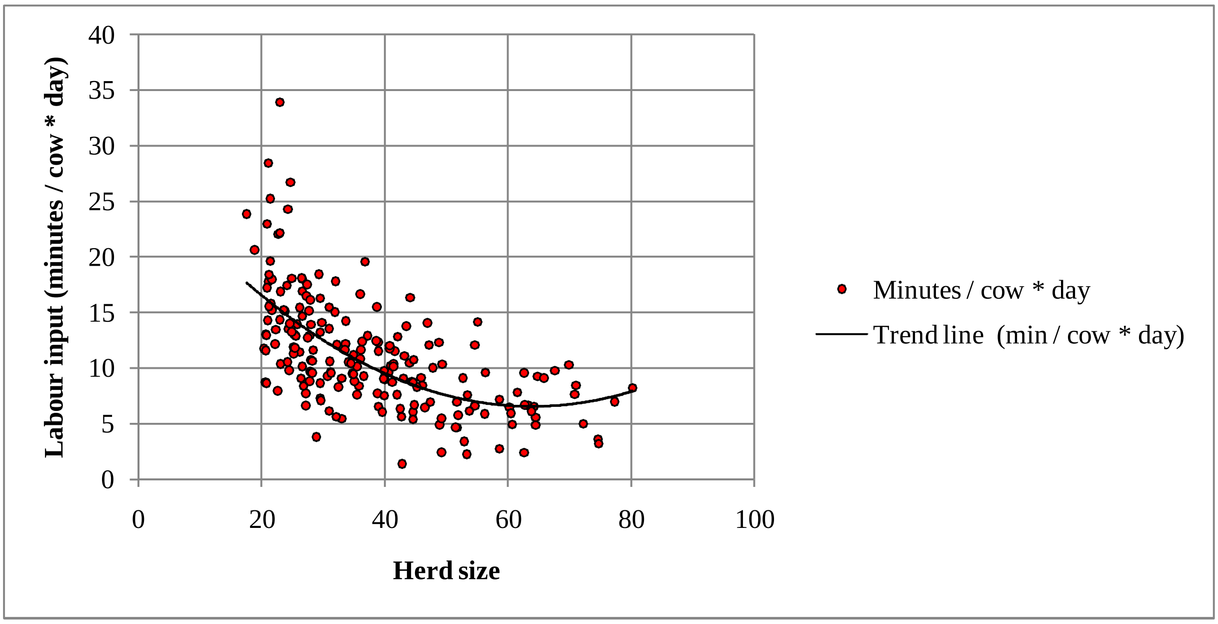

Figure 1: Labour input (min / cow * day) for different herd sizes.

In the further analysis, herd size is replaced by Ln (herd size) according to the "L-shaped" distribution of labour input as a function of herd size (Fig. 1). The results from the separate models, including the different explanatory variables one by one together with Ln (herd size), are presented in Table 1, and the result from the final model including all significant fixed effect variables is presented in Table 2, both models together with the corresponding *P*-values.

Table 1: Estimated effects of housing conditions on required labour input (min / cow *day). Results from simple models were one fixed effect variable is adjusted for Ln (herd size). (Mean herd size: 38.0 ± 14.5 cows, range: 17.6 – 80.2).

Variable name	**Class**	**n**	**Estimate**	**Std. Error**	**P-value**
Milk yield / 1000		201	0.32	0.31	0.30
Replacement area (m^2 per cow)	0.00	24	-0.38	1.06	0.72
	0.01 - 3.00	63	0.32	0.85	0.71
	3.01 - 6.00	80	-0.49	0.82	0.55
	> 6.00	34	0.00		
Building type	Remodelled	109	1.32	0.57	0.02
	New building	92	0.00	.	.
Building form	Rectangular	68	-1.30	0.67	0.06
	2 wings	47	-0.60	0.72	0.41
	> 2 wings	86	0.00		
Milking system	Milking parlour	166	2.83	0.82	< 0.001
	AMS	35	0.00		
Floor type	Solid floor	86	-0.17	0.59	0.77
	Slatted floor	115	0.00		
Number of cubicle rows	1-2 rows	62	1.87	0.69	0.01
	4-5 rows	65	0.47	0.67	0.49
	3 rows	74	0.00		
Cubicle location	Combinations	41	0.72	0.72	0.32
	In an own section	38	-0.33	0.75	0.67
	One side of feed table	122	0.00		
Separation of dry cows	No	128	-0.29	0.61	0.63
	Yes	73	0.00		
Separation pens	No	59	1.57	0.64	0.01
	Yes	142	0.00		
Roughage feeding	Manual	14	0.58	1.47	0.69
	Tractor with feeder / feeder mixer wagon	62	-0.72	1.09	0.51
	Feeder	108	-0.25	1.04	0.81
	Others	17	0.00		
Roughage store	Round bales	43	1.32	0.76	0.08
	Tower silo	37	1.82	0.80	0.02
	Horizontal silo	27	0.77	0.90	0.39
	Others	24	1.72	0.93	0.07
	Missing	70	0.00		
Cleanliness score		201	-0.18	0.10	0.07
Farmers' attitude	Indifferent	15	0.62	1.11	0.58
	Missing	87	-1.29	0.62	0.04
	Disagree	19	-1.21	1.01	0.23
	Agree	80	0.00		

Table 2: Estimates for required labour input for significant housing conditions in the final model (min / cow *day).

Fixed effect	Class	Mean ± SD	n	Estimate	Std. Error	P-value
Intercept			201	-50.91	22.44	0.02
Ln (Herd size)		3.57 ± 0.37	201	16.19	6.19	0.01
Milk yield / 1000		7.06 ± 0.92	201	8.40	2.88	< 0.01
Milk yield / 1000 * Ln (Herd size)			201	-2.25	0.81	0.01
Building type	Remodelled		109	13.80	5.33	0.01
	New building		92	0.00	.	.
Remodelled * Ln (Herd size)			109	-3.75	1.48	0.01
New building * Ln (Herd size)			92	0.00	.	.
Milking system	Milking parlour		166	23.47	10.55	0.03
	AMS		35	0.00	.	.
Milking parlour * Ln (Herd size)			166	-5.38	2.70	0.05
AMS * Ln (Herd size)			35	0.00	.	.
Number of cubicle rows	1-2 rows		62	1.57	0.67	0.02
	4-5 rows		65	0.63	0.65	0.34
	3 rows		74	0.00	.	.
Separation pens	No		59	0.85	0.61	0.17
	Yes		142	0.00	.	.
Cleanliness score		15.8 ± 2.8	201	-0.16	0.10	0.09
Farmers' attitude	Indifferent		15	0.08	1.04	0.94
	Missing		87	-1.62	0.57	0.01
	Disagree		19	-1.31	0.94	0.16
	Agree		80	0.00	.	.

Remodelled barns with less than 39 cows had higher labour input compared to new barns (Fig. 2). Remodelled barns often have more complex layouts, and 68 % of the barns had more than two wings while the equivalent figure for new barns was 13 %. Rectangular building form tended to be associated with lower labour input compared to layouts with two wings and more in the simple model. However, this effect was not significant in the final model.

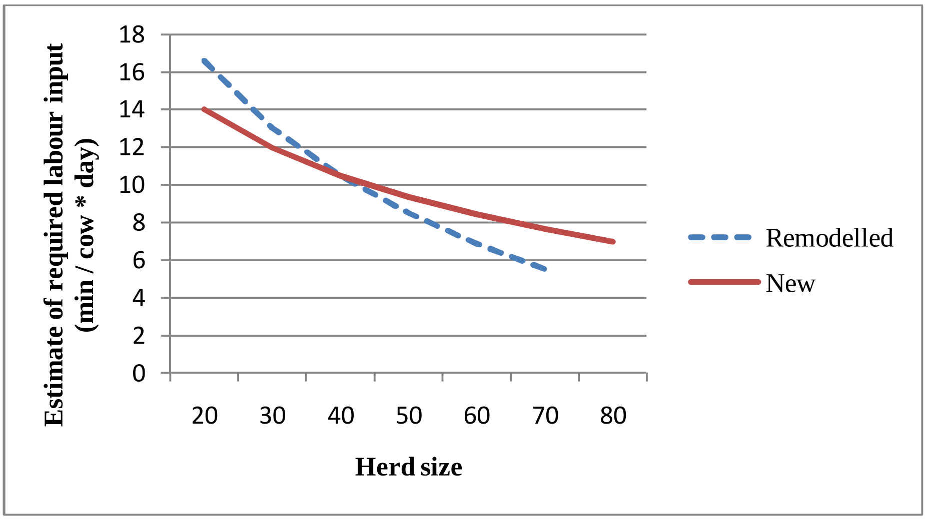

Figure 2: Model estimates of required labour input in remodelled and new barns.

Among the larger herds, many had invested in AMS (mean herd size on AMS-farms: 53.2 ± 12.4, range: 28.9 – 77.3 cows) and barns with AMS had significant lower labour input. However, the estimated labour input per cow was not affected by herd size in AMS barns. Hence, the difference between milking parlours and AMS is decreased by increasing herd size (Table 2) as visualized in Fig. 3.

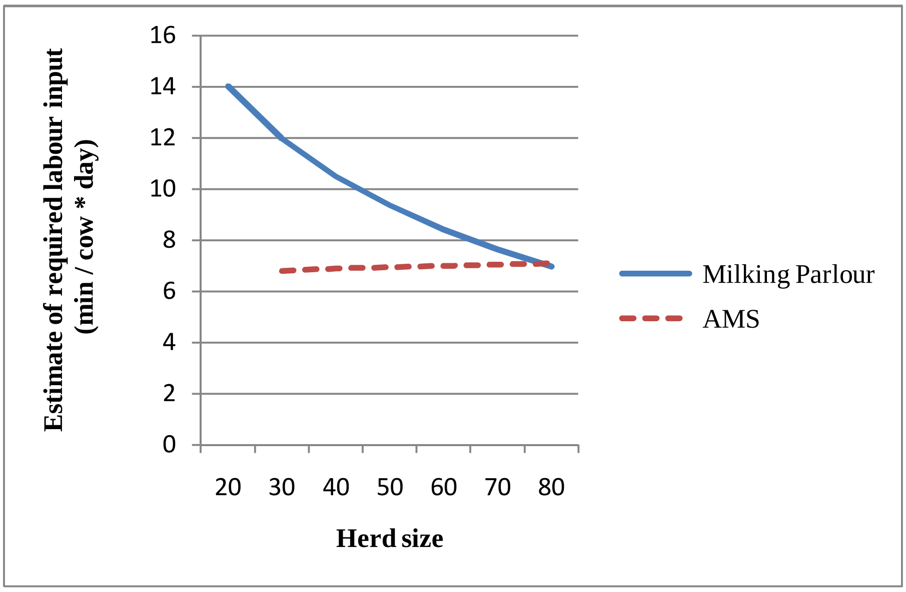

Figure 3: Model estimates of required labour input in barns with milking parlours and AMS.

Barn layouts with 1-2 cubicle rows had significantly higher labour input compared to 3-row layout in the final model (Table 2). The location of the cubicles, however, had no effect on the required labour. Alley floor type, represented by solid or slatted floor, did not affect the required labour either.

The space allocated for replacement area (m^2 / cow), nor the possibilities for separating dry cows, had any effect on the labour input. However, separation pens for special needs cows, tended to contribute to a lower required labour input (Table 1 and 2).

Storing roughage in tower silos was associated with higher labour input in the simple model (Table 1), yet this variable had no significant effect in the final model (Table 2). The way of feeding roughage did not affect the labour input.

According to the final model the labour input decreased by increased milk yield per cow from herd sizes of 23 cows and more. For a mean sized herd (38 cows) this effect was estimated to - 9.4 (min / cow * day) for an increase in milk yield of 1000 litres.

Herds with more dirty cows (high value in the cleanliness score) tended to have lower labour input even in the final model (Table 2). Farmers agreeing in the statement that “animals experience physical pain as humans do” tended to have higher labour input in the simple model (Table 1). However, in the final model this variable had only limited effect (Table 2).

4 Discussion

The results from the present study show that the labour input per cow decreased by increasing herd size up to approximately 60 cows, which is in accordance with Nygaard (1977) and later Auernhammer (1990). The required labour might be lower in even larger herds. However, according to Hedlund (2008), milking is the only reason for reduced labour when herds increase from 100 to 400 cows.

In the present study there was also an interesting interaction between herd size and milking system. Labour input decreased by increasing herd size in herds with traditional milking parlours, while it was constant in herds with AMS. When using the AMS, the milking unit has a certain capacity (Hyde and Engel, 2002), and changes in the herd size that remain within the capacity of one AMS will only to a small extent affect the required labour input. In herds with milking parlours however, the capacity will depend on type of milking parlour (Jakobsson, 2000; Wagner et al., 2001), size and how it is equipped (Smith et al., 1998; Schick, 2000). Installing AMS represents a high investment (Næss and Stokstad, 2010), yet, especially in countries with high labour costs, like Norway, such an investment might be profitable.

Compared to new barns, remodelled barns had a higher labour input, but only up to a herd size of 39 cows. It seems reasonable to suggest that remodelling barns with > 40 cows will be rather comprehensive, and thus achieve a similar functionality and mechanization level as new barns. Both Ekelund and Dolby (1993) and Bewley et al., (2001a) reported that in general new cubicle barns provide a more desirable environment, and are thus more labour efficient than remodelled cubicle barns, although initial investments were higher. Even though the final model is adjusted for herd size, barns with three cubicle rows had significant lower labour input compared to barns with 1-2 rows. Small farms may have less opportunity to invest in labour-saving mechanization. Though remodelled barns had a more complex layout, the number of wings or location of cubicles did not affect the required labour in the final model. Properly designed barns seem to have good functionality independent of these parameters. There was no significant difference in labour input between barns with different alley floor types, which seems reasonable as any of these systems hardly involve any labour input for removing manure from the alleys.

Access to pens for special needs cows had a weak tendency to reduce the labour input in the final model estimate (Table 2). Graves et al., (2006) stated that a well designed section for special needs cows will decrease the need of labour input and simplify the veterinary work. This is also supported by the work of Vasseur et al. (2010), and who in addition points out the positive effect on animal welfare. The amount of replacement area per dairy cow did not affect the labour input. There were replacement calves and heifers in all herds and the differences have probably been too small to affect the need of labour.

The roughage feeding was more or less mechanized on all farms, which might explain why roughage feeding method did not affect the labour input per cow. According to the final model there was no significant effect of roughage storing method on required labour input, possibly because many farms used single wrapped round bales in addition to their main storing method for roughage. Round bales or silage bags are normally stored outside the barn (Bickert et al., 2000), and it will take additional time to collect and strip them.

Decreased labour input in herds with high yielding cows may seem surprising. On the other hand, it is possible that farmers with high yielding herds have more focus on management and efficient work. High yields are correlated with healthy cows, which also will reduce the required labour input.

According to the final model, herds with cleaner cows tended to have a higher required labour input. Proper cleaning and provision of sawdust in cubicles takes additional time, but will also contribute to cleaner cows (Ruud et al., 2010). Farmers who disagree in the statement "animals experience physical pain as humans do" had a weak tendency to spend less time for the dairy work. This might reflect the interests of the farmers and how they prioritize their work. However, the volume of the work does not necessary reflect the quality.

5 Conclusions

The variation in labour input per cow was large between farms, but it generally decreased by increased herd size up to approximately 60 cows. Barns with AMS had the same estimated required labour input independent of herd size, whereas in herds with milking parlours labour input decreased by increasing herd size from 20 to 80 cows. The estimated required labour input was higher for rebuilt barns up to a herd size of 39 cows. The comprehensive variation in labour input indicates that optimizing building layout, developing good management routines and proper mechanization levels, would considerably reduce the required amount of labour.

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