Observational and Experimental Studies of the Influence of Housing Factors on the Behaviour and Health of Dairy Cows

Jan Hultgren

Department of Animal Environment and Health
Skara

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Abstract

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Livestock housing conditions are an important determinant of animal behaviour and health. The objective of the present work was to elucidate the influence of some important housing factors on the occurrence of production diseases in dairy cattle and to clarify the relationship between experimental and observational methods in the study of disease patterns in dairy herds. The importance of the animals' cleanliness is emphasized and consequences for their behaviour, cleanliness, health and well-being of different types of tie-stall equipment are considered. In particular, the influence of electric cow-trainers on the animals' health and welfare is discussed in light of the present work and previous research. Important effects on foot, leg and udder health in relation to a transition from tie-stalls to loose housing systems are also dealt with.

Effects of electric cow-trainers on common clinical diseases, reproductive performance and risk of culling were studied by comparing lactation records from Swedish cow-trainer herds with historical and contemporary control records in herds without cow-trainers. Exposure to cow-trainers increased the incidence risk of silent heat, clinical mastitis and ketosis, and changed silent heat from being a neutral disease with respect to culling to a major risk factor. The cow-trainers increased the general negative effect of diseases on the cows' reproductive performance and risk of culling.

The influence of a rubber slat flooring system for tie-stalls on animal behaviour, cleanliness and foot health was studied in a controlled trial during two housing periods in an experimental dairy herd. In half of the stalls, the rearmost part of the solid flooring was replaced with nine rubber-coated 53 mm wide slats, divided by 29-mm slots. Stalls with rubber slats were equipped with ethyl-vinyl-acetate mats in the front part and littered with small amounts of wood shavings daily, while stalls with a solid floor had standard rubber mats and received large amounts of chopped straw daily as bedding. Cows on the rubber slatted floor lay down more easily than those on the solid floor, and rose normally and without any increased risk of slipping. However, there was some evidence of a preference for a solid floor when lying. Cows on the rubber slatted floor were much less dirty on their hindparts than those on the solid floor, and at hoof trimming, the prevalence of hygiene-related foot lesions in hind feet was several times lower in the rubber slat system.

In order to study the effects of changes in housing system on foot/leg and udder health, retrospectively collected monthly herd records from Swedish dairy herds were utilized. Significant increases in the incidence of veterinary-treated foot and leg disorders were found up to 18 months after changing from tie-stalls to cubicles and the incidences of clinical mastitis and teat injuries were decreased beyond 18 months after changing from tie-stalls to cubicles or straw yards. Later than 18 months after rebuilding, herds that shifted from long-stalls to short-stalls had less foot and leg lesions than those remaining in long-stalls.

Keywords: dairy cattle, housing, electric cow-trainer, rubber slatted floor, bedding, animal behaviour, cleanliness, rebuilding, fertility, silent heat, animal health, mastitis, teat injury, somatic cell count, foot and leg disease, ketosis, culling.

Author's address: Jan Hultgren, Department of Animal Environment and Health, SLU, P.O.Box 234, S-532 23 SKARA, Sweden; *e-mail:* jan.hultgren@hmh.slu.se

Our doubts are traitors,
And make us lose the good we oft might win
By fearing to attempt.

William Shakespeare (1564-1616)
'Measure for Measure'

To whom it may concern,
be willing or stubborn

Contents

Appendix

Papers I-IV

This thesis is based on the following papers, which will be referred to in the text by their Roman numerals:

I. Oltenacu, P.A., Hultgren J. & Algers, B. 1998. Associations between use of electric cow-trainers and clinical diseases, reproductive performance and culling in Swedish dairy cattle. *Preventive veterinary medicine 37*, 77-90.

II. Hultgren, J. 2001. Effects of two stall flooring systems on the behaviour of tied dairy cows. *Applied animal behaviour science*. In press.

III. Hultgren, J. & Bergsten, C. Effects of a rubber slatted flooring system on cleanliness and foot health in tied dairy cows. Submitted for publication.

IV. Hultgren, J. Changes in housing of Swedish dairy herds: incidences of veterinary-treated foot and leg disorders, clinical mastitis and teat injuries, and prevalences of high milk somatic cell counts. Submitted for publication.

Introduction

Dairy production in Europe and Sweden

Background

During the past 50 years, dairy production in the industrialized world has undergone a revolution. Dairy farms are now highly mechanized and computerized installations, farmers have become enterprising businessmen and cows have turned into production units. To stay in business, dairy producers must continue to increase their production efficiency and the development towards more intensive production systems continues. Health status is an important determinant of a cow's milk production, reproductive performance and longevity in the herd, and great attention is payed to minimizing losses due to health problems (Dijkhuizen and Morris, 1997). Two of the most common and costly production diseases are udder and foot disorders (DeGraves and Fetrow, 1993; Frei *et al.*, 1997; Kossaibati and Esslemont, 1997; Noordhuizen, 1998).

At the middle of the 20th century, farmers usually kept several types of animals, *e.g.* cattle, horses, swine and poultry. When housed, cows were generally tied. During the fifties, sixties and seventies, farm animal production was specialized to one type of animal and one branch, *e.g.* milk production or pork production. Loose housing with deep straw bedding for dairy cows became popular in the fifties (Larsson, 1955a; Hörning, 2000) and the cubicle system was introduced in the early sixties (Albright and Arave, 1997; Hörning, 2000). The number of animals per herd rose and housing facilities, including systems for feeding, milking and manure disposal, became increasingly mechanized. Almost or completely strawless tie-stalls in combination with slurry handling were common in Europe when rebuilding during the sixties and seventies. Since the eighties, there has been a strong striving towards cubicles and simple housing solutions to reduce investment costs. Family-based agriculture has a strong tradtition in Europe (Galeski and Wilkening, 1987). Swedish dairy farms are still in most cases owned and run by members of a family, with few other employees (Nitsch, 1987), which may limit the capacity for large housing investments.

Due to urbanization and industrialization, the proportion of the population dedicated to agriculture has diminished, as has the number of dairy cattle. In 1960, there were more than 1.2 million Swedish dairy cows (SHS, 1991). In 1985 the number had dropped to 645,700 and in 2000 to 427,600 (Statistics Sweden, 2001, http://www.scb.se: Accessed 14-March-2001). Between 1985 and 2000, the number of Swedish dairy herds went down from approx. 30,100 to 13,100. Similar declining trends were seen in other European countries. The Swedish official milk recording scheme (OMRS) is administered by the Swedish Dairy Association. It collects, processes and stores production and health data from all enrolled herds and supplies farmers, advisors and researchers with relevant information (Andersson, 1988). In 1985, the OMRS comprised 17,200 herds with 452,000 cows (70% of cow population), and in 2000 9100 herds and 368,400 cows (86% of population) (Swedish Dairy Assoc., 2001a).

Dairy cows' body size, milk yield and manure production, as well as the average herd size is increasing. Fig. 1 illustrates the almost linear trends for these parameters in Swedish dairy herds during the last four decades. Simultaneously, there has been a demand for less intensive labour and improved working conditions in agriculture, as well as in other sectors of the society. Between 1970 and 1995, the estimated average labour time per Swedish dairy cow was reduced by almost 50% (SHS, 1996). According to Agger and Alban (1996), Danish dairy farmers spent approximately 30% less labour time per tied dairy cow in 1994 as in 1983. Together these factors illustrate the need for increasingly well-functioning housing facilities in modern dairy production.

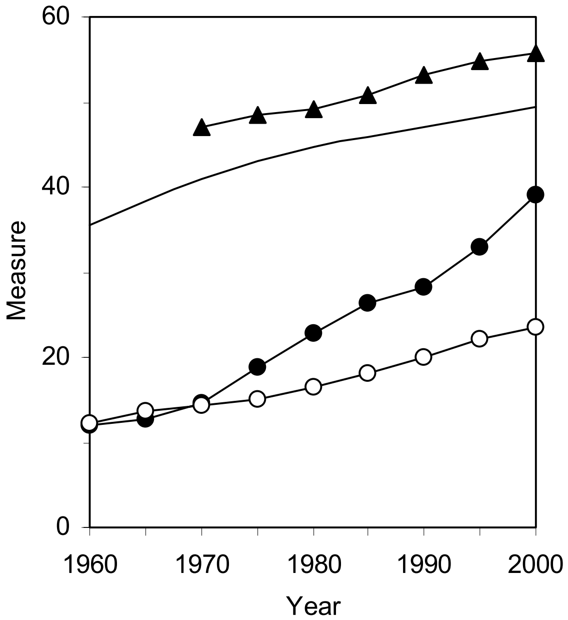

Fig. 1. Average herd size (●), milk yield (kg ECM cow^{-1} day^{-1}; O), estimated live body weight of first-calvers (x10 kg; ▲) and estimated manure production (kg faeces and urine cow^{-1} day^{-1}; —) in dairy herds enrolled in the Swedish official milk recording scheme 1960 to 2000 (Larsson, 1955b; Overcash *et al.*, 1983; Swedish Board Agric, 1995b; Swedish Dairy Assoc., 2001a).

At the present Swedish production level, the amount of faeces excreted increases by approx. 3% for every extra 1000 kg ECM produced per year, but the excretion is greater if the ration is based on a high rather than on a low percentage of roughage (Swedish Board Agric., 1995b).

The two major Swedish dairy breeds are the Swedish Red and White (SRB) and the Swedish Holstein (SLB). The SRB has its roots in the Swedish Red and the Swedish Ayrshire breeds, which were combined in 1927 (Korkman, 1953). Since then, there has been an exchange of semen mainly with Norway and Finland. Towards the end of the 19th century, Friesian cattle were imported from Germany, and later also from the Netherlands, to form the SLB breed (Korkman, 1953). Since 1970, the import of North American Holstein semen has been extensive and the SLB breed has moved towards the international Holsteins. Presently, the main import of semen is from North America and the Netherlands (Hååard, M., Svensk Avel, Skara, Sweden, 2001, pers. comm.). The SRB is the prevailing of the two breeds, with 48% of all dairy cows in the OMRS, while 46% are SLB (Swedish Dairy Assoc., 2001a). In 1960, these percentages were 67 and 23%, and in 1980 they were 58 and 31%, respectively.

During the last two decades, public concerns, national legislation and regulations stipulated by the European community, have put animal welfare and the prevention of production diseases in focus. Most farmers' organizations and companies, *e.g.* dairy and slaughter cooperatives, have adopted policies and programs to guarantee animal health, well-being and product quality to consumers, implying restrictions in animal housing and management. Ethical quality has become an issue and adds significant value to animal products.

The Swedish animal welfare regulations regarding farm animal husbandry were adopted in 1993, based on the animal welfare act and statute of 1988. The regulations have been implemented stepwise since then. They prescribe a certain minimum stall length and width for each type of stall, based on the cows' age and live weight. Housing facilities should be designed to allow the animals to move relatively freely. The floor surface should be even and protect from slipping. Cows should be given access to straw or other comparable bedding at their lying-place.

According to the Swedish statute on animal protection, new technical systems and equipment for livestock must be pretested and approved officially from an animal welfare and health point of view before they are used commercially. The Swedish Board of Agriculture decides upon when and how the pretesting should be done and gives final approval. A similar pretesting procedure has been adopted in Switzerland, in accordance with the Swiss federal act on animal protection (Wechsler *et al.*, 1997; Fröhlich and Oester, 2001, http://www.bvet.admin.ch/: Accessed 29-March-2001), and in Norway (Norwegian Agricultural Inspection Service, 2001, http://www.landbrukstilsynet.no/: Accessed 1-April-2001), but is lacking in other countries. On a Swedish initiative, the European Union Commission has been asked to investigate the possibilities of drawing up common EU rules for pretesting.

Furthermore, Swedish housing facilities for farm animals must be approved when they are built or considerably reconstructed, if they comprise more than a certain number of heads (*e.g.* 10 cows). This official livestock housing approval scheme is implemented and administered by the regional county administrations. Data from the housing approval scheme are compiled yearly by the Swedish Board of Agriculture and may be used to roughly indicate the livestock building activity. During the first half of the 1990's, the percentage of all Swedish dairy installations subjected to approval due to building measures increased from below 1 to 5.2% yearly. In 1996, it dropped to 1.9%, probably to some extent due to uncertainties in connection with the entrance of Sweden into the EU in 1995 and the implementation of a milk quota system, and thereafter started to rise again. In 2000, it was approx. 3.6% (Swedish Board Agric., 1989-2001; Statistics Sweden, 1990-2000). This indicates that political decisions to a large extent influence the incentive for housing improvements.

Rebuilding of a dairy in most cases implies an increased herd size. In 2000, there was an average relative herd size increase of 47% (from 49 to 72 cows) in connection with building measures for dairy cows approved in the housing approval scheme. Since 1988, the relative herd size increase has varied considerably between years (18-49%) (Swedish Board Agric., 1989-2001). In a survey regarding housing conditions in 265 dairy installations in five Swedish counties (the same geographical area as in Paper IV), based on data from the official livestock housing approval scheme from 1990 to 1994, Hultgren (1994) found that uninsulated buildings and loose housing occurred much more frequently when new installations were built than in reconstructed ones, and that new facilities generally housed more cows than reconstructed ones.

Organic farming is adopted increasingly in Europe (IFOAM, 2001, http://www.ifoam.org/: Accessed 29-March-2001). Between 1993 and 1997, the greatest increase in the percentage of organic agricultural land area in Western Europe was seen in Sweden. In 2000, 460 Swedish dairy herds with 18,100 dairy cows (4% of all herds and cows) were affiliated to KRAV (Varhos, D., KRAV, Uppsala, Sweden, 2001, pers. comm.), which is by far the most common Swedish organization for inspection and certification of organic agricultural production and a member of IFOAM (the International Federation of Organic Agriculture Movements). Affiliated herds are subjected to standards aimed at promoting the respect for natural processes and behaviour, strengthen the ties between town and country, and between producer and consumer. The standards comply with the European Union regulations concerning organic production.

Housing and management of cows

In cold climates, housing of dairy cattle is necessary. Dairy cows are regularly housed in the northern parts of Europe and North America, except for a period of grazing in the summer. According to national legislation, Swedish dairy cows should be given the opportunity to graze daily for 2-4 months between May and October. In the Netherlands, cubicle housing accounts for more than 90% of the dairy herds (Hopster, H., Inst. Anim. Sci. Health, Lelystad, the Netherlands, 2001, pers. comm.) and in the UK for 76% (Seabrook, M., Univ. Nottingham, Sutton, UK, 2001, pers. comm.). In contrast, tie-stall systems are more common in the north of Europe. Approximately 80% of the Swedish cows are kept tied in either short-stalls or long-stalls and the situation is similar in the rest of Scandinavia. A survey in 1994 indicated that 87% of Danish dairy herds were kept in tie-stalls (Alban and Agger, 1996b). In Switzerland, Frei *et al.* (1997) reported 97% of the dairy herds to be tied and according to Hörning (2000) tie-stalls dominate in Germany, too.

Long-stalls are a traditional North European housing system for tied cattle. As opposed to short-stalls (ordinary tie-stalls), where the cows have access to the feeding table 24 h per day, long-stalls are equipped with lockable feeding barriers (Fig. 2). These are used to immobilize the cows during milking, and usually to lock them out from the feeding table during (part of) the time when the herdsman is not in the barn. Long-stalls are usually 0.4 to 0.5 m longer than short-stalls, to allow for cow movements when the feeding barriers are closed, and equipped with a more elevated feeding table or mangers. Tie-stalls are less common in newly built Swedish dairy facilities and long-stalls are uncommon even in recently reconstructed barns.

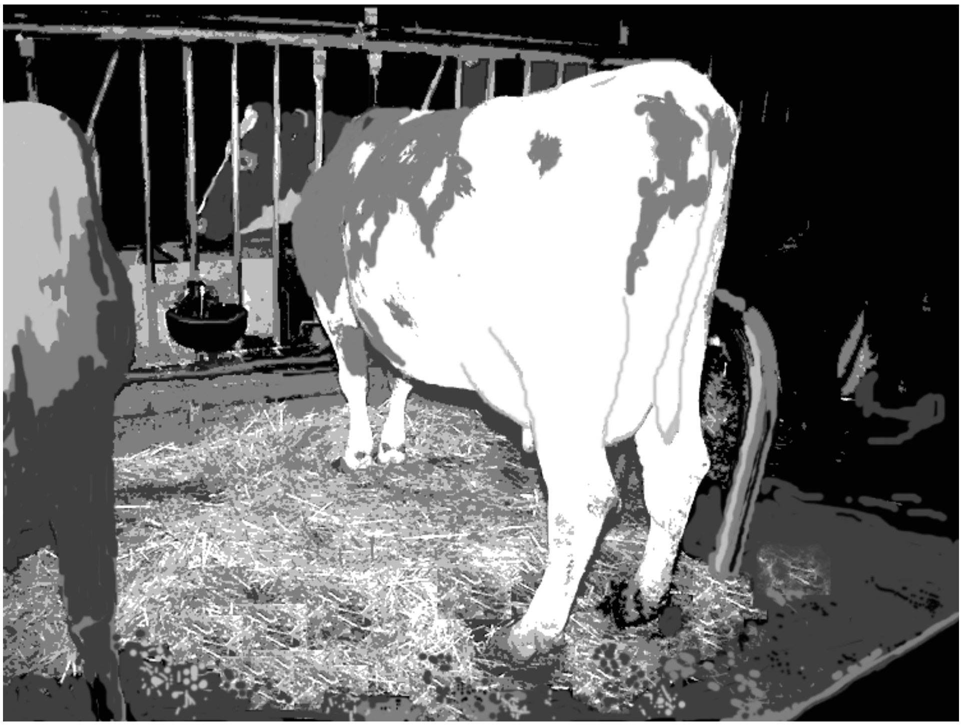

Fig. 2. Long-stall housing. Here, the feeding barriers are open, and the cows have access to the feeding table, place themselves in the front part of the stalls and easily drop manure in the rear part.

The types of feeding barriers and stall dividers used in tie-stalls vary greatly between countries. In Sweden, new and renovated tie-stalls are usually equipped with an individually adjustable type of shoulder rails (a neckbow), that directs the cow's movements in order to keep the stall and the cow clean (Fig. 3). Electric cow-trainers (ECTs) for tied cows are widely used in *e.g.* Germany, Switzerland, Denmark and Norway, but are prohibited in Sweden since 1995 and in Lower

Saxonia, Gemany (Bernard Hörning, University of Kassel, Kassel, Germany, 2001, pers. comm.). Alternatives to the traditional ECT have been developed and tested with some success (Wechsler *et al.*, 2000a).

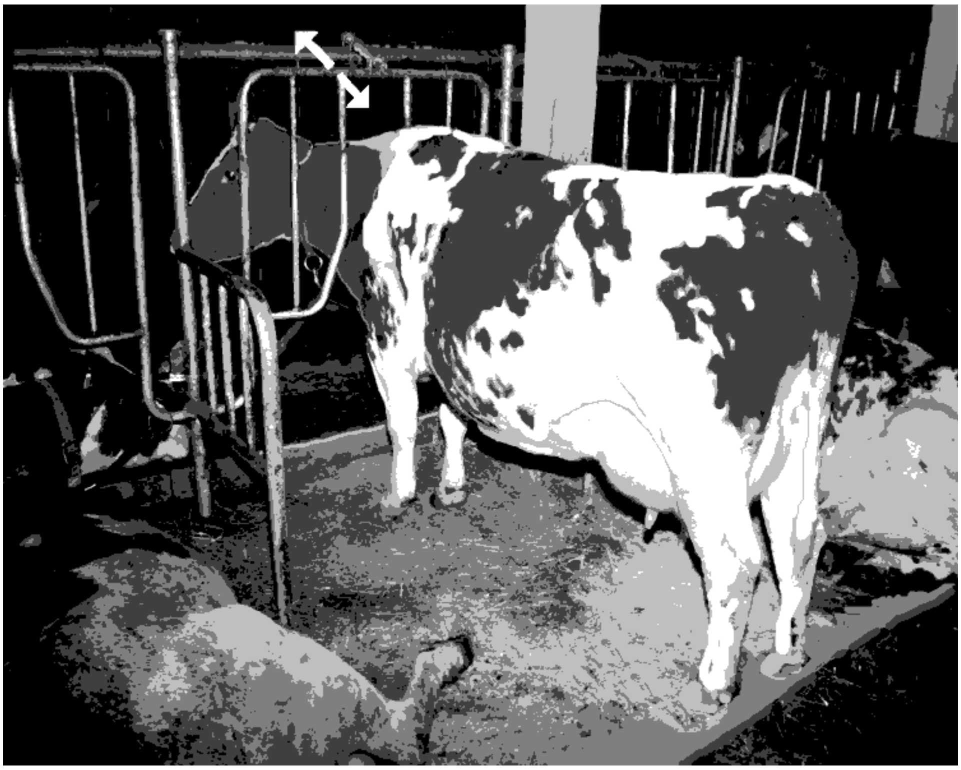

Fig. 3. Short-stall housing with individually adjustable neckbows. The arrows at the top of the picture indicate how the feeding barrier can be tilted to fit the size of the cow and guide her movements.

If the cows are not tied, they may be housed in a cubicle system or in a yard or pen without stalls and divisions, *i.e.* a straw yard or a deep-bedded pack system. All systems where the cows are not tied or in any other way permanently kept in stalls will be referred to below as 'loose housing'. The term 'cubicle' will denote a stall for lying in loose housing (American 'freestall'), regardless of its design. Cubicles may sometimes be used for feeding of roughage, so called feed cubicles, which are then designed similar to short-stalls. Straw-yard systems have been popular for periods, mostly among especially devoted producers. In Northern Europe, they are normally designed as deep-bedded pack systems, *i.e.* indoor straw yards where the bedding is removed once a year. Straw yards without bedding, as the North American 'dry lots', hardly occur at all in Northern Europe. Loose housing is recommended by *e.g.* the Swedish Board of Agriculture, and increases with new dairy facilities. In the IFOAM regulations for organic farming, loose housing is compulsory from 2010. With loose housing, separate stalls along the feeding table, *i.e.* feed stalls (Bergsten, 2001), are becoming increasingly common.

Swedish tie-stalls and cubicles are usually equipped with rubber mats, ethyl-vinyl-acetate (EVA) mats or mattresses, and littered with chopped straw, wood shavings or sawdust. Sand bedding is rare. New types of mats and mattresses are currently being developed and introduced.

Floors are almost invariably made of concrete. Loose-housing alleys may be designed as a scraped solid surface or may have slats. Swedish standard slatted flooring has 125-mm concrete slats, divided by 40 (maximum allowed) or 35 mm wide slots. Concrete slatted flooring is still widely used for both cattle and calves because it is fairly cheap, durable and may contribute to hygienic conditions, although it is well-known that it hampers the animals' lying and walking behaviour (Kirchner and Boxberger, 1987; Drolia *et al.*, 1990; Albright and Arave, 1997; Herlin and Drevemo, 1997). So far, scrapers are not used on top of slatted flooring in Sweden, as is seen in the Netherlands and Germany. Especially in the Netherlands, new types of solid and slatted floors are being developed to meet environmental demands and reduce ammonia emission, without reducing animal welfare (Braam and Swierstra, 1999; Stefanowska *et al.*, 2001). Slatted floors and the increasing application of liquid manure limits the use of large amounts of litter, especially long straw.

Due to the climate of Northern Europe, livestock buildings must consider the ability of the animals to adapt to low temperatures. Thus, tied cows should be kept in insulated buildings. A cubicle system may be placed in either an insulated or an uninsulated building. Straw yards are usually established in uninsulated buildings, to achieve an acceptable indoor air quality. If cubicles are combined with slatted flooring, the building is usually insulated if located in the north of Scandinavia, due to a high risk of freezing and related problems with manure disposal, while it may be uninsulated in the southern part of Scandinavia and in the rest of Europe.

In Scandinavia, the roughage of the feed ration is generally based on grass-clover silage, but in most cases small amounts of hay are also included. The concentrates consist of grains (oats, barley, wheat, triticale), supplemented with commercial protein feeds, minerals and vitamins. Feeding is to a high degree accomplished by using automatic telpher-hung wagons and, in loose-housing systems, electronic concentrate feeders. TMR (total mixed ration) feeding is less common.

Milking is usually done twice daily, occasionally three times. Tied cows are almost invariably milked in their stalls, but a separate milking parlour occurs. Robotic milking is increasingly common in several countries. Presently (March, 2001), there are existing installations at approximately 50 Swedish farms and at least 30 more dairies have planned installations during the next few months (Everitt, B., Swedish Dairy Assoc., Stockholm, 2001, pers. comm.).

Dairy production and cow health

General aspects

All animal husbandry implies a considerable influence on the animals' behaviour, including some restrictions on their freedom of movement. Dairy cows must be fed and milked, and manure must be disposed of with a minimal amount of effort, which limits the space available to the animals. In the wild, cattle would cover long distances in search for pasture (Phillips, 1993). The herd would follow a daily rhythm of walking, grazing, resting and ruminating. The animals would drop their manure and leave it behind them while moving. There is an element of repulsion to the animals' own faeces in their grazing behaviour, as herbage near to faecal deposits is rejected (Phillips, 1991) but, as pointed out by Phillips (1993), the close and constant proximity to manure in cowsheds, may cause habituation to its offensiveness. Thus, although cows have been shown to prefer a soft lying-place (Nilsson, 1988; Herlin, 1997), there is apparently no behavioural patterns in dairy cows to avoid contact with dropped manure when they select a lying area. Possibly, there has not been any need for an evolvement of such a behavioural pattern because the risk of getting in contact with dropped manure was very low in the wild.

When confined to a barn, the behaviour of the animals is to a large extent affected by the design of housing facilities and management practices. Feed may be available 24 h per day, but space is restricted, especially in tie-stalls. Conflicts between cows may arise *e.g.* at the feeding table, the concentrate feeders or the water cups. Concrete floors are fairly cheap and durable, but not very suitable for cows' feet. The lying-place is often far from optimally comfortable, which may make the animals spend much time standing and predispose for foot lesions (Galindo and Broom, 1993; Singh *et al.*, 1993; Leonard *et al.*, 1994).

Since the space for housed cattle is restricted and the cows do not avoid contamination with manure, they easily get dirty. Moreover, exposure to novel environments and stress, which housed cattle frequently encounter when they are handled, often leads to increased elimination (Albright and Arave, 1997), which further enhances the risk of contamination. In any type of cow stall, there is in fact a conflict between demands for cleanliness and the cow's freedom of movement, *i.e.* the more space given, the higher the risk of contamination with manure (Hultgren *et al.*, 1998b). Poor cleanliness probably reduces the animals' comfort. The risk of itch, pain, wounds and infections increases. Both foot lesions and mastitis are to a high degree caused by unsatisfactory hygienic housing and management conditions (Oz *et al.*, 1985; Klastrup *et al.*, 1987; Bergsten and Pettersson, 1992; Rodríguez Lainz, 1996; Barkema *et al.*, 1999). Moreover, milk quality may be impaired, and consumers may consider the conditions to be ethically unacceptable. The herdsman also has to put more effort into the cleaning of stalls and animals. By improving the hygienic conditions at strategic points in the barn and on the animals, diseases may probably be prevented to some extent.

Not only has the amount of faeces and urine increased during the last decades, but there is also good reason to assume changes in the composition of the manure, due to a different diet for dairy cattle. There is a striking difference in faeces consistency between dairy and beef cows, which clearly shows the influence of feeding intensity. The faeces of dairy cows has definitely become more liquid during the last decades. It might also have become more adhesive and possibly contains more of noxious substances, although this has not been investigated scientifically. Such changes would most likely contribute to impaired animal cleanliness and health.

In order to keep stalls for tied cows cleaner, alternative feeding barriers (neckbows) have been developed (Rom, 1989), that guide the cows' movements. The effects of such feeding barriers on animal cleanliness, behaviour and health have not been evaluated extensively enough. Since they interfere with the cows behaviour, they might increase the risk of abnormal behaviour and behaviourally evoked health disturbances, *e.g.* injuries and foot lesions due to difficulties in lying down and(or) rising and an abnormal eating stance, as discussed by *e.g.* Hennichs and Plym Forshell (1984), von Groth (1985) and Lidfors (1989). Rom (1989) compared neckbow ties with yoke, neckbar and double chain ties, and counted the number of physical interactions >500 N between the cow and the equipment. He found that the neckbow and yoke ties resulted in the most such interactions. The number of interactions with the neckbow tie increased dramatically with the width of the manger and decreased with its height. Furthermore, the neckbow tie implied a risk of strangulation and of getting stuck under the rails.

Electric cow-trainers have been introduced under the assumption that they improve labour efficiency and reduce health problems related to feet and legs by improved cleanliness in tie-stall systems. Indeed, the use of ECTs has been shown to improve the cleanliness of the stalls (Simensen and Sjaastad, 1988; Bergsten and Pettersson, 1992; Bergsten *et al.*, 1992) as well as that of the cattle (Bergsten and Pettersson, 1992; Bergsten *et al.*, 1992). In Sweden, installations of ECTs were especially common when rebuilding and changing from long-stalls to short-stalls. The Swedish Board of Agriculture (1994b) estimated that ECTs were used in 4.7% of all Swedish dairy herds, or 8.3% of all cows, in 1993. The possibly harmful effects of ECTs have been discussed in several countries (*e.g.* Hultgren, 1989; Swedish Board of Agriculture, 1994b; Rådet for dyreetikk, 1994, http://org.nlh.no/etikkutvalget/: Accessed 13-March-2001; Wechsler *et al.*, 2000a).

In slatted floors, the width of the slots is a compromise between good drainage and concerns about animal behaviour and health. Good drainage promotes a dry and clean floor surface with a low risk of slipping (Albutt *et al.*, 1990). The slats must be wide enough to give sufficient support for the hooves and so avoid a high pressure on them (Kirchner and Boxberger, 1987) while, on the other hand, the drainage increases if they are made narrower. Svennerstedt (1999) found that good manure drainage from dairy cows can be achieved using 125-mm concrete slats with 30-mm slots between them (a ratio of 125/30), and Nilsson and Svennerstedt (2000) that a ratio of 53/30 was satisfying for rubber slats, of the type used in Papers II and III. Preliminary results from recent Swedish model experiments with dairy cow manure show that approximately the same drainage capacity is achieved for a ratio of 75/20 as for 125/30 (Magnusson, M., Swedish Univ. Agric. Sci., Alnarp, Sweden, 2001, pers. comm.).

One way to improve the hygienic conditions in tie-stall barns, without reducing the cows' freedom of movement or applying ECTs, is to use slatted flooring in the rear of the stalls, thereby draining faeces and urine. Since litter easily decreases the drainage capacity of the slatted floor (Nilsson and Svennerstedt, 2000), only small amounts of finely chopped straw, wood shavings or other comparable bedding can be used on slats. To compensate for the relative lack of litter, the solid front part of the stall may be covered with a soft mat. Since the seventies, one type of manure-draining rubber slat system for tied cattle has been designed and used in a Swedish beef herd of foster cows (Nyberg, R., Nyköping, Sweden, 1999, pers. comm.), and was later developed for use in dairy production (Fig. 4). In 2000, based on the studies presented in Papers II and III, the system was pretested and approved for cows and heifers in tie-stalls and feed cubicles.

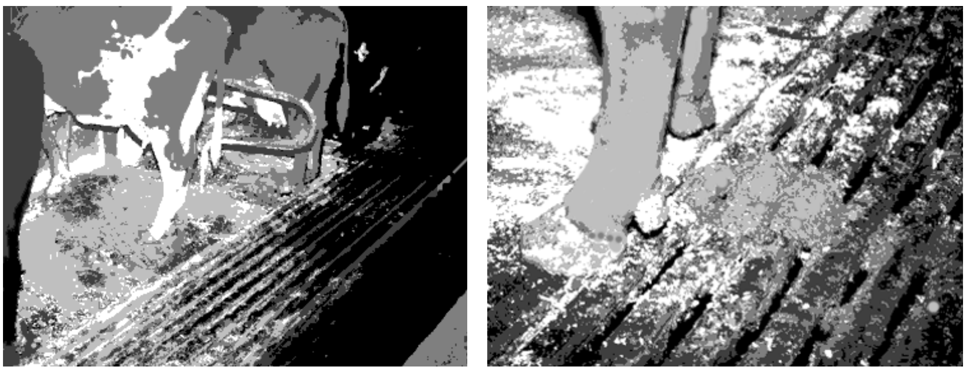

Fig. 4. Manure-draining rubber-coated slatted floor in tie-stalls, from the study in Paper II and III. The rearmost 0.74 m of the stall has been replaced by nine 53-mm slats.

When reconstructing dairy facilities or when changing from one housing system to another, one would expect transitory disturbances in equipment, machinery and management, resulting in increased animal health risks and decreased productive performance. In general economic terms, transitions from one production system to another have been proposed to cause so called growth costs (Penrose, 1959; Renborg and Karlsson, 1969) or growth sacrifices (Olsson, 1988). Such sacrifices should be taken into account when deciding upon a change in farm animal housing and handling facilities, *e.g.* at a dairy farm. In any study of effects of housing systems, care must be taken to avoid confounding by the age of the building, by the animals' or the herdsman's incomplete adaptation to a new housing system or by other factors related to the building process.

Besides their economical consequences, animal health disturbances may have serious welfare implications. Animals' discomfort is not always reflected by reduced productive performance. Hoof diseases are long-lasting and in many cases painful to the affected animal, causing severe lameness, and even severe cases are often overlooked by the herdsman. Therefore they are of major animal welfare concern, even if milk production sometimes remains unaffected. In contrast, the local inflammatory signs of clinical mastitis are often mild, and more dramatic cases are mostly treated within one or two days. Mastitis might thus have less serious animal welfare implications, although surprisingly little has been done to study the welfare aspects of udder disorders. The great attention drawn to mastitis is instead due to its dramatic effect on milk production and quality.

Udder and foot health in relation to housing

Inflammation of the cow's mammary gland is the most common and costly disease in dairy production (DeGraves and Fetrow, 1993; Swedish Dairy Association, 2001b). Elevated milk somatic cell counts (MSCCs) are an indication of subclinical mastitis (Andersson, 1988; Reneau, 1986). Tramped teats have been shown to be an important risk factor for clinical mastitis (Bendixen *et al.*, 1988b; Oltenacu *et al.*, 1990; Elbers *et al.*, 1998).

Teat injuries and mastitis have been found by many investigators to be more common in tie-stall systems than in loose housing (Bakken, 1981; Blom *et al.*, 1985; Bakken *et al.*, 1988; Bendixen *et al.*, 1988a and 1988b; Vecht *et al.*, 1989; Empel *et al.*, 1991; Krohn and Rasmussen, 1992; Edler and Grunert, 1995; Saloniemi, 1995b; Valde *et al.*, 1997). Ekesbo (1966) found that both teat injuries and mastitis occurred less commonly when a soft lying area was used, but no clear influence of the housing system itself was found. Saloniemi and Roine (1981) found a higher incidence of teat disorders in short-stalls than in long-stalls, cubicles or straw yards, but no effect of the housing systems on the incidence of mastitis. Berry (1998) and Peeler *et al.* (2000) found a higher incidence of clinical mastitis in straw yards, when compared to cubicle housing. Similarly, Bareille *et al.* (1998) reported an association of straw-yard housing (*versus* cubicles) with increased MSCCs, and with clinical mastitis without systemic signs of illness. According to Bakken (1982), the influence on prevalences of subclinical *Staph. aureus* mastitis of long- and short-stalls depends on the type of feeding barrier used. Faye *et al.* (1997) found loose housing in straw-yard systems with a high stocking rate to be especially unfavourable for udder health, when comparing with less crowded straw yards or cubicles. Hindhede and Enevoldsen (1993), comparing the health of cows in straw yards with tie-stalls and cubicles, found only minor effects of housing systems on udder health. Østerås and Lund (1988) found no difference in clinical mastitis prevalence or MSCCs between long- and short-stalls, and Koskiniemi (1982) no consistent difference in incidences of teat injuries between long- and short-stalls. Rubber stall mats lower the risk of slipping for tied cows (Gjestang and Løken, 1980), which is likely to reduce the risk of teat injuries.

Nygaard *et al.* (1981) studied 1312 herds and Hansvik Sæther (1994) 444 herds in Norway and both reported a significant increase in the incidence of tramped teats when using ECTs. Bakken (1982) studied 319 Norwegian herds and found an effect of ECTs on the prevalence of subclinical mastitis. Østerås (1991) showed an association between the use of ECTs and teat injuries. However, Østerås and Lund (1988) reported no udder health effects associated with ECTs in Norwegian herds with a problem of high MSCCs, and Matzke *et al.* (1992) reported a small improvement in udder health in herds in southern Germany.

Some of the most prevalent contagious and hygiene-dependent foot lesions are interdigital and digital dermatitis, and heel horn erosion (Andersson and Lundström, 1981; Murray *et al.*, 1996; Rodríguez Lainz *et al.*, 1996). The occurrence of both foot dermatitis and heel erosion has been shown to be associated with poor ambient hygienic conditions (Bergsten and Pettersson, 1992; Rodríguez Lainz, 1996). Laminitis and related lesions, such as sole and white line haemorrhages and sole ulcer, are related predominantly to other environmental factors, such as the hardness of the flooring (Bergsten, 1994; Bergsten and Frank, 1996). In cases of lameness treated by veterinarians, interdigital phlegmon (interdigital necobacillosis, footrot) and acute laminitis are common diagnoses (Nylin, 1980; Alban *et al.*, 1995; Swedish Dairy Assoc., 2001a).

Reports on the influence of housing systems on foot and leg health give a somewhat divided picture. Several authors have found clinical cases of foot and(or) leg disorders to be more common in loose housing than in tie-stalls (Blom, 1982; Rowlands *et al.*, 1983; Thysen, 1987; Faye and Lescourret, 1989; Alban *et al.*, 1995). Alban *et al.* (1995) reported the incidence risk of interdigital phlegmon in Danish cows to be 3.7 times higher in loose housing than in short-stalls. On the other hand, Alban (1995) found no effect on lameness of loose housing *versus* tie-stalls. Blom (1981), Thysen (1987), and Amon and Mavsar (1996) reported more leg injuries in tie-stall systems than in cubicles, Krohn and Rasmussen (1992) more leg injuries in tie-stalls than in a straw yard, and Empel *et al.* (1991) higher incidences of both foot and leg diseases in short-stalls than in cubicles. Foot lesions found by professional hoof trimmers, *e.g.* dermatitis, heel horn erosion, sub-acute or chronic laminitis, and sole ulcers, are generally much more common in loose than in tied cows, as judged by Danish and Swedish prevalence records (Thysen, 1987; Bergsten and Herlin, 1996; Vaarst *et al.*, 1998) and by studies in Belgian herds (Maton, 1987). In an observational study of 5013 dairy cows in 102 herds in southwestern Sweden, the crude prevalence of all foot lesions at hoof trimming was 87% in tie-stalls and 98% in cubicles (Manske, T., Swedish Univ. Agric. Sci., Skara, Sweden, 2001, pers. comm.). Ninety percent of the loose-housed cows had lesions in their front feet, but only 39% of the tied cows. However, Hindhede and Enevoldsen (1993) found no significant effect of housing systems on the prevalence of laminitic lesions or heel horn erosion. According to Frankena *et al.* (1992), sole ulcers are more common in cubicle systems than in straw yards. Beaudeau *et al.* (2000) found the incidence rate of lameness to be higher in cubicles than in straw yards. Singh *et al.* (1994) noted a marked decrease in the incidence of sole lesions (presumably sole ulcers and haemorrhages) in a herd that was moved from a cubicle system to a straw yard.

Bergsten and Pettersson (1992) and Bergsten *et al.* (1992) reported that the use of ECTs improved cleanliness and reduced the prevalence of heel horn erosion. The studies comprised four Swedish commercial dairy herds with a total of 196 cow-stalls, half of which were exposed to ECTs. The herds were observed during one housing season. Foot health was assessed in connection with hoof trimming. The effect of ECTs on the occurrence of other diseases or cow behaviour and reproductive performance was not studied.

Rubber stall mats reduce the risk of hoof lesions related to laminitis (Bergsten, 1994; Bergsten and Frank, 1996). On the other hand, Wechsler *et al.* (2000b) compared the frequency of leg injuries between cubicles with straw bedding and soft mats (with small amounts of straw or sawdust), and found more hairless patches, scabs and wounds on hocks in cows on mats. Nilsson and Walberg (1979) studied gratings with a surface of rubber instead of steel, and found no differences in the occurrence of leg injuries. Insufficiently drained and scraped alleys in loose housing increase the risk of heel horn erosion and the need for veterinary treatment of other foot disorders, compared to concrete slatted flooring (Coehen, 1980; Buchwald *et al.*, 1982; Maton, 1987). On the other hand, badly designed concrete slats in loose housing result in hoof and leg trauma (Kirchner and Boxberger, 1987).

In only a limited number of observational studies carried out in commercial dairy herds, the possible influence on animal health of the age of the housing facilities or of a recent reconstruction appears to have been considered (Ekesbo, 1966; Bakken, 1981; Blom, 1981 and 1982; Bakken, 1982; Koskinieki, 1982; Maton, 1987; Bakken *et al.*, 1988; Saloniemi, 1995b; Valde *et al.*, 1997). One of these studies was carried out in Swedish herds (Ekesbo, 1966). Very few authors have described animal health effects of the different phases of a reconstruction process. Hughes *et al.* (1997) studied mastitis incidences in two herds, 1-3 years after transition from cubicles to a straw yard, and found no significant changes. Näsi and Saloniemi (1981) recorded udder, foot and leg injuries in one experimental herd changing from long- to short-stalls and in another herd changing from an old cubicle system to a new one, following the herds for at least

1.5 years after the housing changes. They reported a gradual improvement of hoof condition, but no other clear effects.

Vaarst *et al.* (1998) found a relation between the occurrence of sole ulcers and udder-related disorders. An association between poor foot health and high incidences of clinical mastitis was also found by Arvidson (2000). Ekman (1998) found the hooves to be better trimmed in herds with constantly low bulk MSCCs than in herds with high cell counts. Østerås (1991) showed a weak association between poor hoof conditions and teat injuries. Most probably, hoof overgrowth and lameness cause teat injuries and mastitis (Saloniemi, 1995a), but the found associations may also be due to common causal factors for both disease entities. Bakken (1982), Østerås and Lund (1988) and Valde *et al.* (1997) considered the inclusion of hoof care routines and(or) hoof condition in the analysis of udder health traits, but only Østerås and Lund found a significant preventive effect of hoof trimming on mastitis.

Data on veterinary treatments of Swedish livestock are stored in the national animal disease recording system (Emanuelson, 1988), governed by an agreement between the Swedish Board of Agriculture and the Swedish Dairy Association. Since 1984, it comprises all farm animals and is available through the OMRS. For all cows in herds enrolled in the OMRS, the risk of having subclinical mastitis is estimated monthly on a scale from 0 to 9 (udder health classes), based on individual MSCCs from the last three test months. A scoring of 6 or higher corresponds to a cell count (adjusted for breed, milk yield, parity and stage of lactation) of approximately 300,000 cells or more per ml at the two to three last monthly recordings, or a risk of approximately 0.6 or more of having a subclinical udder infection (Funke, 1989; Brolund, 1990).

During the period from 1984 to 2000, the lactational or yearly incidence rate of veterinary-treated diseases in Swedish dairy herds enrolled in the OMRS varied between 0.15 and 0.23 for clinical mastitis, 0.01 and 0.03 for teat injuries, 0.02 and 0.04 for hoof diseases, and 0.30 and 0.57 totally (SHS, 1985-1998; Swedish Dairy Assoc., 1999-2001a), which is illustrated by Fig. 5. Based on MSCCs, the true incidence rate of infectious mastitis during the same time period was estimated to be between 0.59 and 0.66 cases per cow-year and the prevalence of subclinical mastitis 26-32%, the estimates being somewhat higher for the SLB breed than for SRB.

From Fig. 5 it may be concluded that the udder health situation in Swedish dairy herds was relatively stable during the covered time period and that the treatment incidence rate of mastitis, teat injuries and hoof diseases varied only marginally, although a decrease during 2000 can be noted. The total treatment incidence showed a more irregular pattern and dropped substantially during the period (the figures were calculated as yearly incidences until 1988 and later as lactational incidences), without any strong relationships with the presented disease-specific incidences. The relatively high treatment incidence of mastitis and total treatment incidence in 1995 and the somewhat low incidences in 2000 were not reflected by corresponding departures from the trend in estimated true mastitis incidences or prevalences, and were probably due to shifts in farmer and veterinary policies for disease treatment and(or) reporting, caused by *e.g.* economic MSCC restrictions applied by the dairy cooperatives, the launching of a new animal disease reporting system or shifts in the price of field veterinary services.

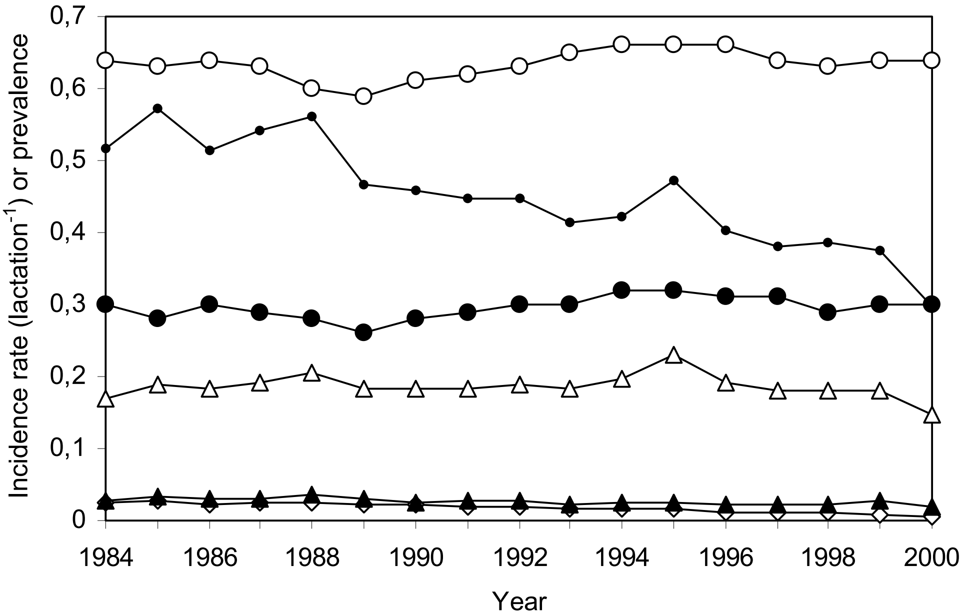

Fig. 5. Number of veterinary-treated cases of mastitis (Δ), teat injuries (◇), hoof diseases (▲) and all diseases (•) per cow-year (1984-88) or per finished or interrupted lactation (1989-2000), and estimated true yearly incidence rate (O) and prevalence (●) of infectious mastitis, in herds enrolled in the Swedish official milk recording scheme 1984-2000 (SHS, 1985-98; Swedish Dairy Assoc., 1999-2001a).

The vast majority of cases of foot diseases in Sweden are treated at routine hoof trimming, which is generally performed once or twice a year (Hultgren *et al.*, 1998a). Therefore, incidence estimates based on veterinary-treated cases alone may depart greatly from true incidences. The information about true incidences and prevalences of foot and leg lesions in Swedish dairy cows during the last decade is however scarce. In an observational study of 102 herds in southwestern Sweden 1996-98, 90% of all cows were affected by at least one foot lesion at hoof trimming (Manske, T., Swedish. Univ. Agric. Sci., Skara, Sweden, 2001, pers. comm.). Among 2011 cows in 50 of these herds, the prevalence of moderate to severe heel horn erosion was 46%, of severe sole haemorrhage 15% and of sole ulcer 14% at hoof trimming in the spring (Bergsten *et al.*, 1998). Although the definition of different types of dermatitis in the feet of cattle is obscure, the subacute erosive or ulcerative form of digital dermatitis is probably an increasing dairy herd problem in Sweden, while the chronic papillomatous form of digital dermatitis occurs only sporadically (Bergsten, C., Swedish Univ. Agric. Sci., Skara, Sweden, 2001, pers. comm.). The prevalence of most foot lesions increases during the housing period (Andersson and Lundström, 1981; Bergsten and Pettersson, 1992). Since foot diseases generally last for most of the lactation and most animals recover during the grazing season (Andersson and Lundström, 1981; Singh *et al.*, 1993), prevalences at hoof trimming in the spring should be fairly good estimates of the lactational (or yearly) incidences.

Health and performance

Health disturbances may reduce the performance of a dairy cow by a number of mechanisms, *e.g.* reduced feed intake, altered feed digestibility and effects on various physiological processes (Dijkhuizen and Morris, 1997). Reproductive failure causes either longer calving intervals or premature culling. The most common causes of culling in Swedish dairy cattle (Swedish Dairy Assoc., 2001a) are reduced reproductive performance (26%), udder illness (17%), low production (9%) and foot/leg diseases (5%). Lowered performance implies reduced milk revenues and higher costs for replacement, extra labour input and medical treatment. Calculations of the economics of livestock diseases are complicated by a lack of knowledge regarding both occurrence and effects of the diseases. Attempts to estimate costs of production diseases in dairy herds have been made by *e.g.* Kossaibati and Esslemont (1997). Emanuelson and Oltenacu (1998) showed that good stockmanship, as measured by milk production or estrous detection efficiency, reduces the negative effect of mastitis and some other diseases on the risk of culling.

There is a negative relationship between milk production and reproductive performance. Thus, higher milk yields are associated with longer intervals from parturition to first ovulation, regular reproductive functions and conception, a lower conception rate at first service and a higher number of services per cow (Berglund *et al.*, 1989). Milk production decreases with increasing MSCCs. Koldeweij *et al.* (1999) reported a reduction in the daily individual milk yield of 1.29 kg in primiparous cows and 2.04 kg in multiparous cows for each unit increase in $\log_{10}$ (MSCC).

From 1985 to 2000, the production of Swedish dairy cows enrolled in the OMRS increased from 6600 to 8600 kg energy-corrected milk (ECM) per cow-year, and from 4700 to 6400 kg in cows not comprised by the OMRS (Swedish Dairy Assoc., 2001a). Despite the substantial increase in milk production during the last 15 years, a fairly constant culling rate (approx. 38-40%) and average age at culling (63.2 months in 1985 and 60.9 months in 2000), the reproductive performance of Swedish dairy cows has deteriorated only marginally. Within the OMRS, the calving interval increased gradually from 12.6 to 13.1 months, the interval from calving to first service from 82 to 88 days, and the interval from calving to last service from 109 to 121 days, while the number of services per cow remained between approx. 1.7 and 1.8 (Swedish Dairy Assoc., 2001a).

Aims

The present thesis is intended to shed light on the influence of some important housing factors on the behaviour and health of dairy cows, and to clarify the relation between experimental and observational methods in the study of disease patterns in dairy herds. More specifically, the aims were:

- To investigate the influence of electric cow-trainers on the occurrence of several clinical diseases, and to determine if the effects of these diseases on cows' reproductive performance and as risk factors for culling are influenced by exposure to cow-trainers

- To investigate the ability of dairy cows to lie down and rise, and to rest comfortably in tie-stalls equipped with a manure-draining rubber slatted floor in the rear part, an ethyl-vinyl-acetate mat in the front part and wood shavings used as bedding material, as compared with ordinary tie-stalls equipped with standard rubber mats and a chopped straw bedding

- To evaluate the effects of the same rubber slat system on animal cleanliness and foot health in tied dairy cows

- To investigate short-term effects on the incidences of foot/leg disorders, clinical mastitis and teat injuries, and on the prevalence of high milk somatic cell counts, in dairy herds originally kept in tie-stall systems and subjected to major housing changes.

Summary of Materials and methods

Herds, housing and management

The data in Paper I consisted of records from 150 Swedish dairy herds with cows which calved from 1984 through 1988. Thirty-seven herds that installed ECTs in 1986 or 1987 were identified and 33 of them could be included in the study (response rate 89%). The rest of the herds did not use ECTs (population control herds) and were selected randomly to match the ECT herds with respect to size and geographical location. All herds were housed in tie-stalls. All 33 experimental herds reported to use the same type of ECT (Dressör de Luxe, DeLaval AB, Tumba, Sweden). Twenty herds used the recommended power supply (Nervus Mini-Master, DeLaval AB) and the remaining 13 herds used other types of power supplies. The majority of the farmers (28 herds) used the ECTs continuously. Nearly all farmers (29 herds) had the majority of the cows exposed to ECTs. All farmers reported that they adjusted the ECTs when needed. The average daily production in included lactation records was 25.9 kg 4% fat-corrected milk.

In Papers II and III, a quasi-randomized controlled trial (alternating allocation) was carried out during two consecutive housing periods (years 1 and 2) in an experimental dairy herd of 42 Swedish Red and White cows, belonging to the Department of Animal Environment and Health and kept in 2.20-m long-stalls. In 21 of the stalls, the rearmost 0.74 m of the solid floor had been replaced with a new type of slatted flooring (Fritz Foderstyrning AB, Nässjö, Sweden). The slatted floor had nine rubber-coated, 53 mm wide slats and the slots between them were 29 mm wide. The anterior solid part of the stalls with rubber slats had 20-mm EVA mats (Komfort, DeLaval AB, Tumba, Sweden) and each stall was littered twice daily using approximately 1 kg of chopped straw (study week 1 to 17 during year 1) or 0.7 kg of wood shavings (the rest of the study) daily, given in the morning and in the afternoon. These stalls were denoted treatment R. Stalls with a solid floor had rubber mats (Gummimattan Marianne Larson AB, Gothemburg, Sweden) and received approx. 3 kg of chopped straw on a daily basis (treatment S). Long (0.85 m) or short (0.50 m) stall dividers were placed between every second cow.

The cows were individually fed concentrates five times and silage four times daily from computer feeding wagons, according to production. A fixed amount of 2 kg hay was fed manually twice daily to all lactating cows, while dry cows received additional straw. There was one water cup for every cow. All cows were groomed twice daily, when manure was cleaned from thighs, hocks, udder and tails. Regular hoof trimming was carried out in the entire herd at 3-4-month intervals; shortly after housing, half way in the housing period and shortly before grazing. The average yearly milk production of the herd was 10,400 kg ECM.

The study presented in Paper IV included 194 dairy herds in southwestern Sweden, all originally kept in long-stalls or short-stalls and moved to re-constructed or new housing facilities between 1989 and 1995. Of the total of 322 dairy herds eligible for the study, 89 herds (28%) were excluded due to non-response from farmers, 21 herds because reliable data regarding housing or diseases were not available, 12 herds because they were housed in cubicle systems for some time before rebuilding took place and 6 herds because a secondary housing system was used concurrently for more than 20% of the herd. It was estimated that the studied herds constituted one third of all dairy facilities approved for reconstructions in the selected counties during the same time period and approx. 40% of the installations approved from 1990 to 1994 (Swedish Board Agric., 1990-96). The herds were kept in tie-stalls, cubicle systems or straw yard systems. The average production in studied herds was 7975 kg ECM per cow and year.

Data acquisition

In the presented studies, data from various types of national and regional databases were utilized, as well as information obtained through questionnaires and the authors' own on-farm observations.

Observational studies of commercial herds

In Paper I, calving dates for all cows were obtained from the OMRS and used to define individual lactations. The data consisted of 10264 SRB and 5461 SLB lactation records. The records were classified relative to the calving dates and subsequently divided into four treatment groups. The ECT-exposed group (*after ECT*; 1660 records) consisted of all records in herds that installed ECTs with calving dates after the installation of the ECTs. The records from cows not exposed to ECTs were used as controls and classified as: a) a historical population control (*control 84-85*; 3840 records); b) a historical control (*before ECT*; 1278 records) which was comprised of completed lactations in herds that subsequently installed cow-trainers; and c) a contemporary population control (*control 86-88*; 8232 records). Seven hundred and fifteen records where ECTs were installed during the lactation, were eliminated. Data on disease occurrence and reproductive performance were obtained from the OMRS. Each case of disease implied clinical diagnosis and treatment by the field veterinarian or AI technician. Questionnaires were sent to all farmers to collect data regarding housing design and management. Information on housing was also collected by local AI technicians.

In Paper IV, the herds were sampled from the official livestock housing approval system in five (out of 24) counties (Fig. 6), from which data on housing design, building measures and management were collected. Questionnaires were sent to all farmers to obtain information regarding dates for building start and finish, and housing system before and after rebuilding. For each herd, monthly records of production, veterinary-treated cases of foot/leg and udder diseases and individual MSCCs were collected from the OMRS for a period before onset (3444 records, range 1-45 months, mean 10.7 months) and after finish (3727 records, range 0-59 months, mean 11.4 months) of the rebuilding. Comparisons were made between different transition phases (before rebuilding, and 0-6 months, 6-12 months, 12-18 months and >18 months after rebuilding) and between different changes of housing system (either remaining in the same tie-stall system, shifting from long- to short-stalls, shifting to cubicles or shifting to a straw yard). Data from the building period were not considered.

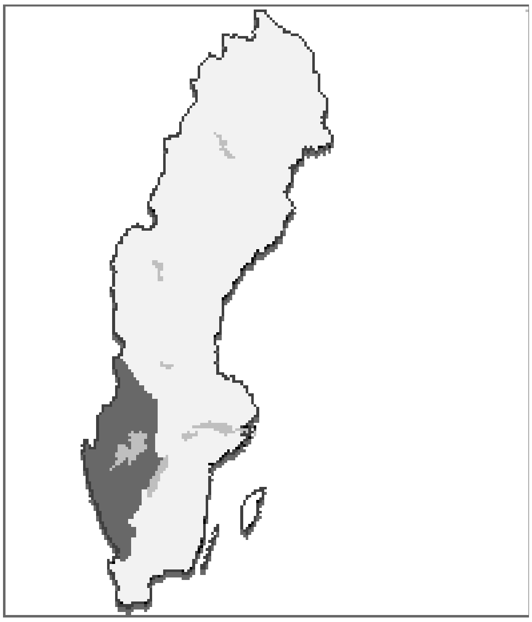

Fig. 6. Map of Sweden, showing the geographical area (shaded) covered by the study presented in Paper IV and representing approximately 28% of all Swedish dairy herds at the time of the study.

Records of behaviour

In Paper II, 13 animals receiving treatment R and 13 S animals were matched pairwise for parity, days in milk, daily milk yield, type of stall divider (short or long) and body side turned towards the stall divider (left or right). No primiparous cows were included before 100 days after calving, to allow for a sufficient time to adapt to the housing. In order to obtain conditions for behavioural recordings, seven animals in each stall row had to be moved, which was done 2 weeks before the start of the behavioural observations. Behaviour was recorded from April to May (study days 1-38). The animals were observed during two 24-h periods each, using video recordings (time-lapse with two frames per second). One camera was used, mounted on the milking rail behind and above the stalls. For practical reasons, two adjacent cows (placed between two stall dividers) on one stall side were filmed simultaneously each day. Cows within matched pairs were in most cases filmed on consecutive days. A random order of recording within matched pairs was applied. All video-tapes were read and de-coded by one person, noting date, time of day and each occurrence of behavioural events.

Lying-down and rising movements were divided into two phases each, and three different resting postures were defined, in accordance with Schnitzer (1971) and de Wilt (1985). *Lying-down phase 1* covered pendling head movements when preparing to lie down, and lasted until the first front knee touched the floor, while *lying-down phase 2* was the rest of the lying down, until the chest rested on the floor. *Rising phase 1* started when the chest was first lifted and ended when both hind feet were placed on the floor, while *rising phase 2* was the rest of the rising sequence, ending when both front feet were placed on the floor. The average time for *lying-down phase 1*, *lying-down phase 2*, resting (lying time per bout), resting in adjacent stall (proportion of total lying time), *rising phase 1* and *rising phase 2* was calculated. Furthermore, the total lying time per 24 h, the average time for lying bouts and the percentage of the total lying time spent in different resting postures was calculated for each cow. Occurrences of slipping were noted. The cows of one matched pair were omitted for coming into estrous. The final data consisted of 12 observations, one for each cow-pair.

Records of cleanliness

Contamination of animals with manure (Paper III) was scored by the same person once a week during year 1 and once every second week during year 2. The observations were made in the morning before grooming and milking, so the animals had been exposed to the different floor types for at least 12 h without any cleaning measures. For practical reasons, the recording was not blinded.

The extent of contamination with faeces or urine on the hind parts of the cows was assessed visually on a 4-level ordinal scale (*0* = no or almost no contamination with manure; *1* = one solitary large spot or several small spots of manure, together covering less than a fifth of the total area; *2* = one solitary spot or several small spots of manure, together covering between one fifth and half of the total area; *3* = more than half of the area covered by manure). Nine separate body divisions were rated. The recording scheme was developed for the specific purpose of the study, based on previous practical experiences. Within each cow record, the scores were added to form three sum scores, representing three principal body parts, referred to below as *foot* (the dorsal part of the claws, the pastern and the dew claws of the hind feet), *leg* (above the foot and including the hock area of the hind legs) and *body* (the gaskins, the thighs, the rump, the areas around the ilial and ischial tuberosities, and the udder). The three sum scores were transformed into three dichotomous outcome variables. A total of 1781 cow cleanliness records were obtained from 73 cows.

Records of foot health at hoof trimming

Claw measurements and assessments of foot lesions (Paper III) were carried out in all cows in connection with hoof trimming three times yearly. Claw measurements included toe length, measured with vernier callipers, and lower toe angle, measured with a special angle meter at the distal part of the dorsal toe wall, before trimming.

Severity and extension of dermatitis, heel horn erosion and sole lesions were assessed in all hind feet on 4-level ordinal scales, according to Bergsten (1995) and later reduced to 2 levels. Thus, dermatitis was coded as *0* (skin of the foot intact) or *1* (exudative or hyperkeratotic/proliferative dermatitis; erosions and(or) ulcerations), and heel horn erosion as *0* (intact heel horn or superficial loss of horn) or *1* (marked fissures or craters). Sole and white line haemorrhages were coded as *0* (no haemorrhage or only slight haemorrhagic discolouration) or *1* (extensive and(or) distinct, more profound haemorrhage, not disappearing at slight trimming). Sole ulcer was coded as *0* (intact sole horn) or *1* (exposed corium). The presence of wart growth, interdigital hyperplasia, white line separation, double sole, and abnormal claw shape was also noted. Similar recordings had been made during the housing period prior to the study. Three veterinary researchers were engaged in the recording. At each trimming occasion, all recording was made by the same veterinarian. Trimming and recording were performed outside the cowshed, and the recording veterinarian was not aware of the exposure status of examined cows. Between trimmings, any of two veterinary researchers recorded all new cases of foot diseases. A total of 330 cow foot health records were obtained from 82 cows. Two hundred and forty records were used in the final analysis.

Statistical methods

In Paper I, the effect of parity, treatment group and occurrence of diseases on production and reproductive performance measures were estimated using linear least squares models, including herd as a fixed effect. To analyze the effect of parity and of exposure to ECT on the risk of diseases and culling, and the effect of diseases on the risk of culling, logistic regression models were used. The analyses were performed using the GLM and CATMOD procedures in the SAS statistical package (SAS Institute Inc., 1985). According to dispersion parameters, there was no need to account for herd effects. Each breed was analysed separately. Expected incidence rates of diseases for each exposure group were calculated from least-squares means. Conditional odds ratios (*OR*) were obtained from the differences between least-squares means for compared groups. To assess the effect of exposure to ECTs, the exposed group was compared with the historical experimental control (*before ECT*) and the contemporary population control (*control 86-88*).

For the study of behaviour in Paper II, the two 24-h periods were compared using Student's *t* test for matched pairs in JMP 3 (SAS Institute Inc., 1998). Since no significant within-cow differences were found ($P \geq 0.10$), overall means per cow were calculated. For outcome variables with near to Normal distribution, before or after logarithmic transformation, as judged by visual examination of histograms, the analysis was done using Student's *t* test for matched pairs. For obviously skewed data (time resting in adjacent stall and time for *rising phase 2*), the sign test (Altman, 1991) was used instead. The percentage of time spent in different resting postures and the frequency of slipping was compared between treatments without using any formal statistical test.

In Paper III, logistic regression modelling was applied, using the generalized estimating equations (GEE) approach (Liang and Zeger, 1986) and the GENMOD procedure in SAS (SAS Institute Inc., 1997). An exchangeable correlation structure was used, assuming all observations to be equally correlated within cow. 'Cow nested within year' was specified as the *subject effect*. Observations of a cow were thus assumed to be correlated only if they were from the same year. 'Exposure status' (*0*; *1*) with respect to flooring system was forced into all models. Potential confounding variables were included only if they changed the regression coefficient for exposure status by >15%.

In the analysis of cow cleanliness in Paper III, 'recording week since the beginning of housing' was used as the *within-subject effect*. The effects of flooring system on the cleanliness of *foot*, *leg* and *body* (dichotomized outcome variables) were tested in three separate models. All models also included effects for type of stall divider and type of litter. Due to the presence of interaction, exposure status was nested within type of divider in the model of *foot* cleanliness. The model of *body* cleanliness contained an independent variable representing daily milk yield. To compare the two floorings, odds ratios were calculated from the logistic regression coefficients.

In the analysis of foot health in Paper III, data from the year before year 1 were included. The foot health status at autumn trimmings was assumed to reflect mainly an influence of the grazing period and not the housing conditions, and these data were discarded. The effects of flooring system on the prevalence of dermatitis, heel horn erosion and sole lesions in cows at spring trimmings were tested in three separate models. 'Trimming occasion since the beginning of housing' was used as the *within-subject effect*. All models also included year. Furthermore, the model of dermatitis included an effect for recording veterinarian, and the model of sole ulcer contained effects for type of stall divider and litter. As for cleanliness, odds ratios were calculated from regression coefficients. Claw measurements were compared between the two floor systems without using any formal statistical test.

In Paper IV, four marginal (GGE) Poisson regression models were applied to analyse the number of cases of disease in relation to the average number of cows in the herd during the entire year (clinical diseases) or number of tested cows each month (MSCC). Data regarding foot/leg disorders and teat injuries were fitted to a true Poisson distribution, while overdispersed Poisson distributions were used in the case of clinical mastitis and MSCCs, to adjust for extravariation.

Herd-month records were regarded as repeated measures of herds. ‘Herd identity’ was introduced as the *subject effect*, to take into account the interdependence of measurements. A first-order autoregressive correlation structure was used, assuming monthly disease data to be decreasingly correlated over time. Effects for transition phase (nested within type of change of housing system), type of change of housing system, year, season, herd size, predominant breed, mean parity, and percentage of cows in early lactation were forced into all models. Variables representing building type (new or remodelled cowshed), building season and length of building period, as well as important interactions, were included when appropriate, as judged by a significant likelihood ratio test. Based on least-squares means for different changes in housing system and different transition phases, incidence rates, prevalences and rate (or prevalence) ratios (*RR*) were calculated.

Summary of Results

Electric cow-trainers, health and reproduction (Paper I)

All results were similar for SRB and SLB cows, and only results for the SRB breed are presented. ECTs were a significant risk factor for ketosis, mastitis, weak estrous and culling. *Before ECT* cows had a lower incidence risk for ketosis than *control 84-85* cows (*OR* = 0.64) but the incidence increased after installing ECTs (*OR* = 1.63). The change was more dramatic for weak estrous, with ECT cows starting with a lower incidence risk than the *control 84-85* (*OR* = 0.72) and increasing after installation of ECTs (*OR* = 2.35). For mastitis, the *control 84-85* and *before ECT* groups had similar incidence risks, but the incidence increased significantly more in the ECT-exposed group (*OR* = 1.40) than in the population over the same time period (*OR* = 1.17). The risk of culling was also higher in the *after ECT* group relative to all control groups (*OR* = 1.17).

Exposure to ECTs had no effect on the incidence risk of retained placenta, cystic ovaries, metritis and foot/leg diseases. With regard to foot and leg diseases, the ECT-exposed cows had a higher incidence risk before installing ECTs (*OR* = 1.20) and the incidence decreased after installation (*OR* = 0.73), but this change is not statistically significant and a downward trend in the incidence of foot and leg diseases was also present in control cows (*OR* = 0.87). Diseases, except for weak estrous and perhaps ketosis, increased the risk of culling. The risk of culling was greater in the ECT-exposed group than in the *control 86-88* group for all diseases, except cystic ovaries, ketosis and milk fever. The disease with the highest risk of culling (*OR* = 3.31) in the exposed group was weak estrous.

Productive and reproductive performance over time in the population (*control 84-85 versus control 86-88*) showed an increase of 11 days in calving intervals, a general decline in all other reproductive measures and a small increase in milk production. Cows in the group exposed to ECTs had a 7 to 8 days longer interval from first to last service and 1.5 to 2.5 kg more 4% fat-corrected milk than control groups. All diseases increased the interval from first to last service, from a minimum of 0.4 days for cystic ovaries in the *before ECT* group, to a maximum of 33 days for cystic ovaries and weak estrous in the exposed group. In *before ECT* cows the only significant disease effect was that of foot/leg lesions, causing an increase of 24 days. But after installation of ECTs, all the diseases considered, including foot and leg lesions, increased the interval from first to last service significantly. When comparing the exposed group with the *control 86-88* cows, it should be noted that for all the diseases considered, the increase in the interval from first to last service relative to healthy cows was statistically significant and consistently larger in the exposed group. The interval for healthy cows was the same in both groups (25.5 days).

Rubber slatted flooring and behaviour (Paper II)

The *lying-down phase 1* was 23% shorter in R (20.8 s) than in S animals (27.4 s). The proportion of time R cows spent resting in an adjacent stall (67.0%) was almost 14% units larger than in S cows (53.3%). No significant differences between the R and S groups were found regarding *lying-down phase 2* (5.14 *versus* 5.04 s), total lying time (730 *versus* 732 min), lying time per bout (52.6 *versus* 57.6 min), *rising phase 1* (3.23 *versus* 4.44 s), *rising phase 2* (3.32 *versus* 3.20 s) and standing time per bout (47.1 *versus* 54.5 min).

In the S group, abnormal lying down was observed in one cow and slipping during lying down in one cow; among R animals one abnormal lying down was seen, and no slipping. Abnormal rising was seen in two cows (21 times) and slipping in four cows in the S group, while abnormal rising was seen in only one cow and no slipping during rising was observed in the R group. In one of the S animals, the abnormal rising consisted of lifting the front part first. The cow had not been observed using this type of rising behaviour consistently before the study. The other S cow made repeated attempts to rise at twenty occasions and the R cow made repeated rising attempts twice.

Total lying time varied between cows from 9.0 to 15.1 h per 24 h (mean 12.2 h). The lying time per bout varied between cows from 31.7 to 107.2 min (mean 55.2 min), and the overall variation between bouts was from 8 s to 4.4 h. The total time for the complete lying-down behaviour was on an average 29 s. The time spent for *lying-down phase 1*, *lying-down phase 2*, *rising phase 1* and *rising phase 2* varied between cows from 11.9 to 53.1 s (mean 24.1 s), from 2.6 to 10.0 s (mean 5.1 s), from 1.8 to 12.9 s (mean 3.8 s) and from 2.0 to 5.7 s (mean 3.3 s).

Rubber slatted flooring, cleanliness and foot health (Paper III)

Compared to solid flooring, the rubber slat system was associated with a significantly lower risk of manure contamination on *foot* when short stall dividers were used (*OR* = 0.12), on *leg* (*OR* = 0.39), and on *body* (*OR* = 0.38). Due to interaction, there was only a tendency for a reduced risk of manure contamination on the hind feet when long stall dividers were used (*OR* = 0.51; P = 0.20). There were only small differences in animal cleanliness between the recording occasions. Based on the chosen cut-off points for response variables, the overall percentages of cows considered to be dirty on *foot*, *leg* and *body* on solid and slatted floors, were 91 and 61%, 80 and 43%, and 59 and 35%, respectively.

In comparison with the solid floor system, the rubber slat system was associated with a significantly lowered risk of dermatitis (*OR* = 0.23) and of heel horn erosion (*OR* = 0.09). There was also some indication of a reduced risk of sole ulcer, sole or white line haemorrhage (*OR* = 0.34; P = 0.08). Foot disorders were much less common at the autumn trimming, shortly after housing, than at the two trimmings in the spring, while the differences between the latter were smaller. The prevalences of dermatitis, heel horn erosion and sole ulcer were notably higher in cows tied on the solid floor than in those on rubber slats. No cases of wart growth or interdigital hyperplasia were found. The overall means of toe length and lower toe angle before trimming were 85 mm (SD = 6.7 mm) and 42° (SD = 6.0°) in S cows, while they were 82 mm (SD = 7.0 mm) and 40° (SD = 6.4°) in R cows. There were only small differences between trimming occasions.

The correlation between foot health and cleanliness was low to moderate. Significant Pearson correlation coefficients were found between heel horn erosion and cleanliness on *foot* (*r* = 0.38), *leg* (*r* = 0.42) and *body* (*r* = 0.33), and between sole lesions and cleanliness on *foot* (*r* = 0.36). The three cleanliness outcomes were fairly strongly correlated with each other (*r* = 0.42-0.64).

Rebuilding, foot/leg health and udder health (Paper IV)

Significantly increased incidence rates of foot and leg disorders were found at 0-18 months after building finish when going from long-stalls to cubicles (*RR* = 3.2-4.7), and at 0-12 months when going from short-stalls to cubicles (*RR* = 3.3-3.7). When compared to herds remaining within the same tie-stall system, significant rate ratios were found at 0-12 months when going from long-stalls to cubicles (*RR* = 3.7-5.0) or from short-stalls to cubicles (*RR* = 2.1-7.1). Remaining in long-stalls tended to increase the incidence at >18 months (*RR* = 2.6), while a shift to short-stalls did not. At >18 months herds that stayed in long-stalls had higher incidences than those that had changed to short-stalls (*RR* = 3.3). There was an increased incidence between 0 and 18 months after rebuilding when going from short-stalls to a straw yard, but these herds started out at a higher level than those remaining in short-stalls, and the increase was only significant at 0-6 months, when compared to herds remaining in short-stalls (*RR* = 6.1).

In the analysis of clinical mastitis, there was a general tendency of decreasing disease rates over time. Significant decreases were found at >18 months after building finish when going from long-stalls to cubicles (*RR* = 0.69), at 0-6 and >18 months when going from short-stalls to cubicles (*RR* = 0.70-0.77), and from 6 to 18 months when going from short-stalls to a straw yard (*RR* = 0.20-0.36). Comparing with herds that did not change housing system, a significant rate ratio was also found at 6-12 months when going from short-stalls to a straw yard (*RR* = 0.24). Significant interaction was found between mean parity and transition phase. Before rebuilding, mean parity had practically no effect on clinical mastitis (*RR* = 0.92 for each year of difference), while at 12-18 months after rebuilding, herds with older cows had much more clinical mastitis (*RR* = 6.14*0.92 = 5.65 for each year).

Regarding teat injuries, there was also a general tendency of decreasing disease rates over time. Significant decreases were found at 0-6 and 12-18 months when shifting from long-stalls to cubicles (*RR* = 0.42-0.60), at >6 months when going from long-stalls to a straw yard (*RR* = 0.18-0.24), at >18 months when remaining within short-stalls (*RR* = 0.37), at 0-6 and >12 months when going from short-stalls to cubicles (*RR* = 0.24-0.48), and during the complete period after rebuilding when shifting from short-stalls to a straw yard (*RR* = 0.13-0.40). Comparing with herds that did not change housing system, significant rate ratios were found at >18 months when going from long-stalls to cubicles or a straw yard (*RR* = 0.16-0.25), at 12-18 months when going from short-stalls to cubicles (*RR* = 0.43), and at 0-6 and >12 months when going from short-stalls to a straw yard (*RR* = 0.16-0.36). Remaining in long-stalls meant a significantly decreased incidence at 6-12 months after rebuilding (*RR* = 0.37-0.48), which was not seen when shifting to short-stalls. There was significant interaction between percentage of cows in early lactation and transition phase. Herds with more cows in early lactation had somewhat more teat injuries (*RR* = 2.23 for a change from 0 to 1). At 6-12 months after rebuilding, this effect tended to be the opposite (*RR* = 2.23*0.36 = 0.80), while it was much stronger at >18 months (*RR* = 2.23*3.97 = 8.85), although none of these effect-measure modifications was significant.

In the case of high MSCCs, there were few significant effects. Interaction was found between building season and transition phase and between percentage of cows in early lactation and transition phase. Relative to herds where rebuilding was finished in August to April, there were fewer cows with high cell counts at 12-18 months after rebuilding (*RR* = 0.92) but a tendency of more such cases at >18 months (*RR* = 1.06) if rebuilding was finished in May to July. Before rebuilding, herds with more cows in early lactation had fewer cases of high cell counts (*RR* = 0.53), but at >12 months the effect had diminished (*RR* = 0.70-0.74).

There were no significant differences before rebuilding between herds remaining in long-stalls and herds remaining in short-stalls. The correlation between disease traits was positive and low ($r \leq 0.08$), except between clinical mastitis and teat injuries ($r = 0.30$).

General discussion

Methodological considerations

Reliability of utilized databases

The OMRS and the national animal disease recording system constitute invaluable tools in veterinary research. Since production and disease data are collected routinely from the great majority of Swedish dairy cows, these schemes supply an excellent basis for observational studies. However, their usefulness relies on the quality of indata. *E.g.* housing and management restrictions or price shifts due to the implementation of animal health and welfare policies of dairy or slaughter cooperatives, and changes in the recording routines, may influence incidence estimates to a considerable degree, temporarily or permanently, as mentioned in the introductory section. Such disturbances must be considered in observational studies, if comparisons are made over time. As indicated by Fig. 4, the relatively high treatment incidence of mastitis in 1995 probably did not reflect a truly increased incidence, and might have influenced the results of Paper IV, if not accounted for in the analysis.

Farmers differ with respect to their ability to detect diseases and how often they call for a veterinarian when health disturbances occur. Records of farmer-reported cases of disease are probably more detailed than veterinary records, since the herdsman does not call for a veterinarian every time he notes a health disturbance, but at the same time they are possibly less accurate, due to failure of the farmer to diagnose or report some cases correctly. Moreover, herds with poor managers are more likely to present erroneous (too low or, possibly, too high) rates of clinical diseases. In Paper IV, it was shown that the great majority of all reported cases of the considered diseases were in fact treated by veterinarians. Nevertheless, many mild cases of *e.g.* mastitis and teat injuries are likely to never be reported or even noted by the farmers, although clinically and economically important.

For most diseases, incidences calculated from veterinary-treated cases are underestimates (Bendixen *et al.*, 1988a). This is illustrated by the great difference between the incidence of veterinary-treated mastitis and the incidence estimates based on MSCCs shown in Fig. 4, and by the huge discrepancy between veterinary records of hoof diseases and records obtained at hoof trimming. Some cases are discovered by the herdsman, but the veterinarian is never called for and the animal is never treated because the cow is culled, as a consequence of the disease or for some other reason. Nevertheless, for at least some diseases in Swedish dairy herds, veterinary treatment probably is the most useful definition of a case when studying effects of different housing factors. Basically, this is likely to be true for health disorders that are easy to detect, require veterinary assistance and have a reasonably good prognosis, *i.e.* that are worth while treating, such as interdigital phlegmon. On the other hand, it is less true for diseases like clinical mastitis, since mild cases may be disregarded or overlooked, the disease does not always require veterinary treatment, and farmers may doubt the effectiveness of a veterinary consultation and treatment. Alban and Agger (1996a) showed that Danish farmers to a large extent treated cases of milk fever without calling a veterinarian. For the same reasons, it may be difficult to compare incidences of clinical mastitis between different populations without accounting for cultural, political and economical factors. In the Introduction, this was discussed in relation to variations in the occurrence of mastitis over the years, as measured by Swedish veterinary treatment records.

Poorly accurate disease records may result in information bias. Farmers that installed cow-trainers in Paper I or changed from tie-stalls to cubicle or straw-yard systems in Paper IV were possibly different from other producers with respect to animal health management, which may have resulted in information bias and hence over- or underestimated rebuilding effects. This would be an example of differential misclassification. Likewise, lameness is more easily discovered in loose housing than in tie-stall barns, since the cows show their behaviour more freely. Hence, the veterinarian may be called for more often. The presence at newly built or reconstructed dairies of a chute or crate to immobilize an animal while examining and treating its feet probably contributes to this difference. Consequently, presented incidences of veterinary-treated hoof diseases in old tie-stall barns are probably underestimated to a greater extent than in new loose-housing systems. This is likely to have produced some information bias in Paper IV, resulting in an overestimated effect on hoof diseases caused by a change from tie-stalls to cubicles. Nondifferential misclassification of diseases occurred in Papers I and IV if only a portion of all cases that would have resulted in a veterinary diagnose were actually discovered by the farmers, equally for all study groups. In that case the misclassification led to a bias towards the null.

Swedish field veterinarians are probably called for in nearly all cases of interdigital phlegmon, and in most cases of acute severe laminitis and severe leg injuries, if the farmer judges it more profitable than culling. Interdigital phlegmon is likely to constitute a great part of all cases of foot lesions presented in Paper IV. Due to its marked clinical signs, footrot is readily discovered in any kind of dairy installation and, although some cases of foot dermatitis or sole ulcer may be misdiagnosed as phlegmons, the risk of differential misclassification is probably low.

Theoretically, the official livestock housing approval scheme covers all important building measures in dairy installations of 10 cows or more. Although there are legal possibilites for controlling obedience, the scheme relies to a great extent on the willingness of the individual farmer to apply for approval. It is still assumed that the great majority of all major rebuilding measures in dairy facilities are covered by the scheme (Jacobsson, K., Swedish Board Agric., Jönköping, Sweden, 2001, pers. comm.). Basic data regarding housing design (type of building measure, housing system) for facilities covered by the scheme are likely to be very accurate. However, the scheme contains data from application forms (when the building activities were planned) as well as from final inspections (when the activities were finished). Considerable changes can be made between the original application and the final inspection, which have to be taken into account if the data are to be used in research. To assure the correctness of data in Paper IV, crucial information was confirmed through questionnaires.

Study design, precision and validity

Both the ECT study presented in Paper I and the rebuilding study in Paper IV were designed as retrospective cohort studies, *i.e.* the rate of disease was compared between different study groups, based on historical records. In comparison with case-control studies, cohort studies in most cases allow causal relationships to be demonstrated and entail a lower risk of bias. They are especially suitable for studying the influence of less common risk factors on the occurrence of fairly common diseases. Key items to ensure validity are the criteria for and selection of the exposure groups, equality of follow-up in all groups, and accurate diagnosis of disease (Martin *et al.*, 1987).

In Paper IV, prevalences of high MSCCs were used as a measure of frequency of subclinical mastitis. Prevalence focuses on health status. Diseases with high incidence rates may have low prevalenes if they are short in duration or the diseased animals are rapidly culled. Thus, prevalences can be misleading in etiologic research and are seldom of direct interest. Under the assumption of a stable population and no migration of animals between sub-groups with different incidence rates, there is a simple mathematical relationship between the incidence rate, the duration of the disease and the prevalence (Rothman and Greenland, 1998). These conditions are rarely valid (Miettinen, 1976) and more elaborate formulae have been presented, taking different population parameters into consideration (Preston, 1987; Keiding, 1991). Since these formulae are complicated, it is often not possible in practice to translate prevalences into incidences. Nevertheless, prevalence has been used as the measure of disease occurrence in several observational studies of subclinical mastitis, as indicated by high MSCCs (Bakken, 1982; Valde *et al.*, 1997).

In Paper I, most Swedish dairy herds that had installed ECTs of the most common type in 1986 or 1987 and were enrolled in the OMRS were included. Another 117 herds, matching the ECT herds with respect to size and geographical location, were used as population controls. These controls were selected randomly from the OMRS database. In this case the source population would be all OMRS herds during the covered time period, with a similar size and location to the ECT herds. Due to the high response rate for exposed herds and the applied sampling protocol for controls, the representativity of the sample is probably high, with a low risk of selection bias.

In Paper IV, 40% of the eligible herds were not possible to include in the study. The response rate was 72%. Other reasons for non-compliance (reliable data not available, use of cubicles before rebuilding, two concurrent housing systems) were not likely to have influenced the results to any large extent. There is a low risk that the sample is not representative of the source population, which in this case is all dairy herds in the covered area, enrolled in the OMRS and subjected to the described housing changes between 1989 and 1995. This may have caused selection bias. Roughly one third of all dairy herds subjected to any type of rebuilding activity in the covered geographical area and time period were included.

To assess representativity in Paper IV, the studied herds were compared with other Swedish dairy herds with respect to some production traits. The average herd size the year before (37.7 cows) and after (47.9 cows) rebuilding, and the distribution of herd size data after rebuilding, was similar to corresponding figures for all Swedish dairy installations approved for rebuilding at that time (Swedish Board Agric., 1992-1993). Before rebuilding, the average milk yield (7900 kg ECM per cow-year), the yearly recruitment rate (41.6%) and the number of services per cow (1.72) were only slightly higher than for all OMRS herds, while the calving interval (12.6 months) and the interval from calving to first service (79 days) were slightly shorter (Swedish Dairy Assoc., 2001a). The selected geographical area covered approximately 28% of all Swedish dairy herds, which is the primary level of inference.

By making both historical and contemporary comparisons in Paper I, the influence of differential misclassification due to varying veterinary routines between different ECT groups was reduced. The possibly disturbing effect of population time trends was controlled by including year in the statistical models in Paper IV.

Questionnaires were used to collect complementary information regarding housing and management in Papers I and IV. The questionnaires were sent out and returned by ordinary mail, and in some cases they were supported by telephone calls. Information collected through questionnaires may be doubtful for several reasons. A low response rate decreases the representativity and may result in selection bias. Some types of data are easily misclassified because the answers are unclear, either if they are of a multiple-choice type or formulated as a whole by the respondent. Finally, questions may be badly framed, which decreases the quality of the answers. Therefore, questionnaires should be used with caution. Nevertheless, they are a main source of information in most epidemiological research (Correa *et al.*, 1994; Hartge and Cahill, 1998). In Paper I, questionnaire data were merely meant to describe the herds and their management, and to some extent validate the results. In Paper IV, collected questionnaire data were used for the classification of records into treatment categories. However, care was taken not to misclassify herds with respect to housing system and the information was checked by a telephone call whenever there was any doubt regarding the interpretation of answers.

The study presented in Papers II and III was designed as a controlled trial, based on stratified systematic quasi-random sampling (Martin *et al.*, 1987), ruling out all important bias due to housing, management, feeding or cow factors, and decreasing random variation. For obvious reasons, the recordings of animal behaviour and cleanliness were not blind. All these recordings were carried out by one person, which probably reduced random variation. In the case of foot health, on the other hand, the recordings were blinded to flooring. A variable for recording veterinarian was considered in the foot health models, since the data were not balanced with regard to two of the observers. The risk of systematic differences in assessments of behaviour, cleanliness or foot lesions between the two types of flooring was considered small.

Cow behaviour was recorded by standard methods, using a time-lapse video recording technique. Behaviours were defined in accordance with earlier publications. Observations from adjacent cows that were filmed simultaneously were not completely independent. Herdmates in fact always affect the behaviour of one another, even if the events are separated in space and time. However, the study suggested that the extent that one cow affected the behaviour of another was limited.

Animal cleanliness was recorded according to a new method, developed for the specific purpose of the study. There is no general agreement on how to record animal cleanliness. A scoring systems for cattle was described by Scott and Kelly (1989), but was not considered completely appropriate for tied dairy cows. The skin of cows may be contaminated with faeces, urine, water, litter, or mixtures of these. The contamination may be fresh and wet, old and dry, or both. It may affect only superficial layers of the hair-coat or penetrate deeper, and it may cover the surface of a body part completely or in spots. Finally, different body parts may be affected to a varying extent. Normally, all these characteristics of dirtiness cannot be considered in an experiment, but it is necessary to simplify them into one or a few summary measures. The way this is best done depends on the purpose of the investigation. For instance, in a study of changes in cleanliness throughout the day, it would be important to distinguish between fresh and old manure, and in a study of the effect of cleanliness on hock lesions, it would be necessary to focus on this area of the body and describe it in detail. In dairy cows, the feet and the udder are crucial body parts to consider, since the cleanliness of those parts is known to influence important diseases. In consequence with the aim of the cleanliness study in Paper III, the authors decided to record cleanliness on nine easily definable areas of the hind part, and to subsequently group these into three body parts for the analysis. For obvious reasons, the hind parts were most likely to be affected by the flooring. The tails were not included in the study, since their cleanliness is mainly influenced by the conditions of the gutter, rather than the type of stall floor. Since the cows were groomed and cleaned twice daily, the extension of the contamination, rather than the depth of it or its physical characteristics, was judged as the most relevant measure.

Both the cleanliness and the foot lesion data in Paper III were obtained on a 4-level ordinal scale. To make maximum use of the data, it may have been desirable to maintain the original scaling and use statistical methods for ordinal outcomes. The collapsing of categories results in a loss of information and decrease in power. However, the present study involved repeated measurements and the analysis of correlated ordinal data is cumbersome. More importantly, such an analysis would render the results rather hard to interpret. By dichotomizing the outcome variables, each animal was regarded as either contaminated or not, either diseased or not, with respect to each body part or each foot lesion, in accordance with a simple concept of health, and ordinary statistical methods could be applied.

Several multiple regression techniques were applied to the data. Generalized linear models (GLMs) are an extension of traditional linear models, that allows the mean of a population to depend on a linear predictor through a nonlinear link function and the response probability distribution to be any member of an exponential family of distributions (Nelder and Wedderburn, 1972). GLMs include classical linear models with normal errors, logistic models for binary data (logistic regression) and log models for event data (Poisson regression). Liang and Zeger (1986) introduced the Generalized Estimating Equations (GEE) method for GLMs for modelling marginal means in correlated data, arising from *e.g.* repeated measurements.

In all multivariable models (Papers I, III and IV), independent variables representing relevant confounding factors were tested for inclusion. They were finally included if contributing significantly to the models or judged (on logical or formal statistical grounds) to improve the estimates of the studied exposure factors. Thus, the influence of the cows' breed, age and stage of lactation was accounted for (in Paper III, age and stage of lactation were to some extent controlled by the randomization procedure, and breed effects were controlled by restriction). There is no reason to believe that major confounders have been left out of the analysis, although, as in all statistical modelling, there is no way to assure that this is the case.

In Paper IV, the prevalence of high MSCCs was not included in the model for clinical mastitis, as has been practised by Barkema *et al.* (1999) and others, since both high cell counts and clinical mastitis were regarded as consequences of housing and management, rather than one being a predictor of the other. Because MSCCs were relatively unrelated to housing, it might have been justifiable to include the corresponding prevalence in the model of clinical mastitis, as an indicator of imperfect management.

Multiple regression models were used in Papers I, III and IV. In Papers I and III, the data were fitted to a binomial distribution, and in Paper IV data regarding foot/leg disorders and teat injuries were fitted to a Poisson distribution. Regarding clinical mastitis and high MSCCs in Paper IV, overdispersed Poisson distributions were used, to account for extravariation. When least-squares regression analysis was applied (Paper I), the ability of the models to fit the data was assessed by the overall *F*-test and the adjusted coefficient of determination (R^2). For logistic and Poisson models (Papers I, III and IV), the deviance and scale parameters were used. Residuals were examined by plotting them against predicted values (least-squares regression), and comparing observed and expected means of the outcome variables within strata of discrete covariates (logistic and Poisson regressions) and(or) within deciles of predicted values (Poisson regressions). All models fitted the data relatively well. In Paper I, no sign of overdispersion was found in the data for the logistic regression analyses. In Paper III, there was some indication of overdispersion in the data on cleanliness on the body parts denoted as *leg* and *body*, and regarding sole lesions. It may have resulted from an influence between adjacent cows or production factors, such as milk yield or diet.

The SRB and SLB breeds were analysed separately in Paper I, since important breed differences were suspected, that would have reduced the validity of a summary analysis. However, the models were identical for the two breeds and the results were similar.

In Paper III, there was a very limited number of observations from only one cow herd. Nevertheless, due to the study design, random and systematic variation was low, and significant effects were found for most outcomes. The study presented in Paper I made use of a large number of lactation records regarding clinical diseases and culling, which were assumed to be independent and thus assured a high ability to discern interesting effects. In the least-squares regression analysis of production and reproduction traits in Paper I, 'herd' was included as a fixed effect in all models. Paper IV comprised a limited number of herds, which is likely to have reduced the statistical power, although a relatively large number of repeated measures were used in the analysis. The results suggested that the within-herd correlation between months was strong for high MSCCs, but moderate for foot/leg disorders and clinical mastitis, and low for teat injuries. No formal estimations of power were made. Data presented by Emanuelson (1995) show that the within-herd variation between years in incidence of clinical mastitis is large, while it is only moderate for bulk MSCCs, which is supported by the the present work. Emanuelson assumed that the higher repeatability for MSCCs was due to fewer possibilities for the farmers to affect the measurements by management decisions.

Internal validity refers to statistical inference to the source population, which is the source of subjects for a study, as defined by the selection methods (Rothman and Greenland, 1998). If animals in one specific herd (farm, experimental station, laboratory, *etc.*) are used for an experiment, as in the study in Papers II and III, then, strictly speaking, the herd is the source population and statistical inference pertains only to that herd. Application of the results to other herds would involve a process of generalization. External validity (generalizability) is defined as the certainty to which the inferences drawn from a study pertain to subjects outside the source population (Rothman and Greenland, 1998), or to another level of organization (level of inference). The use of the term generalizability is by no means restricted to observational studies, but seldom practised in experimental research. There is no way to estimate the external validity on formal statistical grounds. Generalization is instead based on subjective judgement, which to some extent may be guided by the similarity of the sample (and the source population) to the group to which inferences are drawn.

Electric cow-trainers (Paper I)

Significant effects of ECTs were found regarding the risk of weak estrous, clinical mastitis, ketosis and culling. ECTs increased the negative effects of diseases on the reproductive performance and turned weak estrous into a major risk factor for culling.

The ECT herds had a higher incidence risk of veterinary-treated foot and leg diseases before installing ECTs and the incidence decreased after installation, but the change was not statistically significant and a downward trend in the incidence was also present in control herds. Possibly, hygiene and foot problems and a desire to correct them were reasons for installing ECTs. Dermatitis and heel horn erosion are the hoof diseases most likely to be positively affected by an improvement of stall cleanliness. Bergsten and Pettersson (1992) and Bergsten *et al.* (1992) reported that the use of ECTs reduced the prevalence of heel horn erosion in two Swedish herds. In the present study, foot and leg diseases did not include cases of heel horn erosion, since these were not treated by a veterinarian. This could explain the lack of a positive effect for this trait.

A negative influence of stress on the ability of the immune system to fight infections, as reported by *e.g.* Broom and Johnson (1993) and an increased incidence of tramped teats and other udder injuries could explain the higher risk of mastitis in cows exposed to ECTs. Nygaard *et al.* (1981) studied 1312 herds and Hansvik Sæther (1994) studied 444 herds in Norway and both reported a significant increase in the incidence of tramped teats when using ECTs. Bakken (1982) studied 319 Norwegian herds and found an effect of ECTs on the prevalence of subclinical mastitis.

The higher frequency of weak estrous in cows exposed to ECTs could be due to failure to express behavioural signs of estrus. Schopper *et al.* (1989) and Hansvik Sæther (1994) reported increased incidences of weak estrous and other reproductive disorders and Eyrich *et al.* (1989) reported a lower incidence of signs of estrus associated with the use of ECTs. Normally, weak estrous responds to treatment and the cow conceives. In animals exposed to ECTs, the treatment was not effective and an affected cow had a high risk of culling. This would indicate that exposure to ECTs changes not only the frequency, but also the nature of the weak estrous disorder. Differences in response to treatment in cows exposed to ECTs could be explained if the condition is caused not only by failure to show signs of estrus but also by imbalances in the reproductive hormones due to stress (Coubrough, 1985). The fact that the interval from first to last service in healthy cows was the same in exposed cows as in the contemporary population control indicated that the overall increase of 7 days for the exposed group is due to both an increase in frequency of diseases and a more negative effect of diseases on fertility in cows exposed to ECTs.

From the point of view of the animal's perception of an electric shock and its biological effects, the body current is probably the most relevant measure of exposure to the shock (Ferris *et al.*, 1936; Norell *et al.*, 1983). Still, *e.g.* the total electrical charge and energy transferred in a shock may be important parameters (Hultgren, 1989). The current produced by a shock of an ECT probably depends to a high degree on the properties of the cow and the stall. Thin claw soles, a wet hair-coat, skin abrasions, poorly insulated ground conditions, wet flooring, absence of a stall mat, contaminated litter, a metallic tie and collar, and a metallic feeding barrier are all likely to enhance ground contact and thus increase the electric current produced in the cow's body (Kirk and Reese, 1982). Consequently, the currents involved in the use of ECTs, and the effects of them on animal behaviour and health, vary considerably between herds, between cows and over time.

ECTs may be used more or less liberally and correctly. By a selective use, clear positive effects on cleanliness and foot health may be attained, as described by Bergsten and Pettersson (1992) and Bergsten *et al.* (1992). On the other hand, the negative effects on reproductive performance, udder health, ketosis and risk of culling presented in Paper I, most likely reflect the overall effect in dairy herds, if ECTs are used in the way they actually were used in Sweden from 1986 to 1988. Since then, housing conditions for dairy cattle and farmers' knowledge about ECTs have changed in some respects, which could possibly cause a different result to be generated if the investigation were repeated at another time. Presently, the Norwegian Department of Agriculture has approved several types of ECTs and ECT power supplies, of which the Minimaster (DeLaval AB) is one (Norwegian Agricultural Inspection Service, 2001, http://www.landbrukstilsynet.no/: Accessed 1-April-2001).

In response to the public debate on ECTs and to obtain more detailed information about the housing of ECT herds, a follow-up study was carried out in 1997, addressing a few mailed questions to the farmers of ECT-exposed herds in

Paper I. Two herds were lost because the owners could not be traced, and 5 herds due to response failure. Thus, responses from 26 herds were collected. In summary, 16 herds were tied in short-stalls and the rest in long-stalls, non-metallic feeding barriers were used in only 2 herds, non-metallic ties or collars were used in 24 herds, and mats were present in at least half of the stalls in 15 of the herds (not published). These data indicate that the stall equipment in the ECT herds was fairly ordinary, and that the cows were probably insulated from ground to a considerable degree and during much of the time. This gives further strength to the results of Paper I.

Rubber slatted flooring (Papers II and III)

Significant effects of a rubber slat system were found on lying-down and resting behaviour, cow cleanliness and hygiene-related hoof diseases in hind feet at trimming.

The phase of lying-down preparations was shorter in R animals than in S animals. With reference to Andreae and Smidt (1982) and Lidfors (1989), this indicates that the cows perceived lying down as being easier in the rubber slat system. The low frequency of abnormal rising and absence of slipping among R animals may support the idea that the cows feel more comfortable when lying down and rising on rubber slats than on a standard rubber mat. The type of flooring and bedding did not affect the total lying time or the lying time per bout, neither through the alleged effect on the ability to lie down, nor through any effect on resting comfort. Lundberg (1999) found a longer time preparing to lie down on a rubber slatted floor than on a solid floor, but this may have resulted from the fact that the compared stall types differed in other important aspects than the type of flooring, rubber mats and bedding, *e.g.* design of stall dividers and placing of water cups.

An alternative explanation for the observed shorter phase of lying-down preparations is that S cows spent more time exploring the bedding material, which then was not related to discomfort during lying down. To eliminate any effect of novelty, studied animals were subjected to the same bedding material several months before the start of the behavioural observations. However, due to the design of the study, the effect of bedding could not be separated from the effect of flooring. Such a confounding of effects could in fact also have existed in several previous studies of lying-down behaviour (Kohli, 1987; Ladewig and von Borell, 1988; Krohn and Munksgaard, 1993).

The longer time lying in an adjacent stall observed in the R group in this experiment, may have indicated that the animals tried to avoid the rubber slats when resting. On the other hand, there was no significant difference between the two flooring systems regarding total lying time or lying time per bout, nor regarding resting posture. The preference for lying on rubber slats *versus* a rubber mat has not been studied previously. All animals had prior experience of concrete slatted flooring as calves, which may have influenced how they perceived a lying area with rubber slats and their ability to lie down and rise in the stalls. Cows without any prior experience of slatted flooring may have felt less comfortable in tie-stalls with rubber slats than cows well adapted to concrete slats in a cubicle system.

Various disturbances, *e.g.* new management routines, new herd-mates or other changes in the environment may prevent the animals from lying down (Castrén, 1988). In the present study, the herd had been kept under the same conditions 18 months preceding the experiment, and primiparous cows were not observed earlier than approximately four months after entering the herd to allow for adaptation.

There was considerable seasonal variation in foot disease occurrence in this study, with prevalences generally getting higher throughout the housing period, which is in accordance with Andersson and Lundström (1981) and Bergsten and Pettersson (1992). This strongly speaks in favour of the practice of a grazing period as a control measure for foot diseases. The differences in prevalence of dermatitis and heel horn erosion between the two types of flooring increased distinctly during the housing period, most clearly seen in year 1. The authors thought this to be mainly, if not only, an indirect effect of the improved hygienic conditions on the rubber slats. No strong correlations were found between foot diseases and preceding cleanliness, but the significant relationships agree with earlier findings that heel horn erosion is associated with poor hygiene.

There was a tendency for a reduced overall prevalence of sole lesions in cows on rubber slats, although both stall types were equipped with mats. It is possible that this reduction was secondary to lower prevalences of dermatitis and heel horn erosion, and thus superior claw horn quality, but it may also have been due to a slightly softer rubber on the slatted floor.

During the first months of the cleanliness and foot health study, chopped straw was used as bedding on both types of flooring, while wood shavings were used the rest of the time on the rubber slats. This change was made because the straw clogged the slots and hampered drainage. Bedding was likely to influence cleanliness and hence a variable indicating litter material was included in the multivariable models.

The rubber slatted flooring was tested in traditional Swedish long-stalls. The effects on cleanliness and foot health would probably have been similar in short-stalls or, in fact, in any type of cow stall. However, if the stalls are kept relatively clean by other means, the effect of the rubber slats would probably diminish, as was seen in the analysis of cleanliness on hind feet, where there was a significant interaction between the type of stall divider and the flooring. It is not possible to conclude from this study which is the optimum design of the rubber slatted flooring (width of slats and slots, percentage of the stall length covered by slats, *etc.*).

Rebuilding (Paper IV)

Following a transition from tie-stalls to loose housing, significant increases were found in the incidence of foot and leg diseases and decreases in the incidences of clinical mastitis and teat injuries. Herds that shifted from long-stalls to short-stalls developed less foot and leg lesions than those that shifted to short-stalls.

The deterioration of foot and leg health when changing from tie-stalls to cubicles may have been caused by an increased spread of infectious agents (Bergsten, 1997), increased levels of stress as a result of novel housing details and mixing of animals, cows not being used to move around or stand on bare concrete or an increased wear of feet due to new concrete flooring (Galindo and Broom, 1993; Ossent *et al.*, 1997; Smart and Cymbaluk, 1997), accidents due to slipping (Wlcek and Herrmann, 1996), deliberately less frequent hoof trimming before the housing change to counteract the increased hoof wear on fresh concrete, or improperly designed installations (Bickert and Cermak, 1997; Weary and Taszkun, 2000). The transitory nature of foot/leg effects indicated that the causative factors diminished with time and(or) that animals and herdsmen adapted to them. In the present study, herds that stayed in long-stalls had increased incidences of foot and leg disorders beyond 18 months after rebuilding, when compared to herds that shifted to short-stalls. Näsi and Saloniemi (1981) found a gradual improvement of foot health in one herd up to 1.5 years after changing from long- to short-stalls.

The improvement of udder health after changing to loose housing is probably explained by a combination of a large number of housing and management factors known to have a great impact on udder health (Oz *et al.*, 1985; Klastrup *et al.*, 1987; Ekman, 1998). *E.g.*, adequately designed stalls allow the cows to lie down and rise without difficulty, thus reducing the risk of teat tramps, and guide their eliminative behaviour, in that way keeping the lying-place cleaner. Efficient ventilation keeps the air in the cowshed clean and reduces draught. Improved milking routines and milking hygiene reduces the trauma inflicted upon the teats during milking and the risk of transferring pathogens. Bakken *et al.* (1988) found that the difference in incidence of clinical mastitis between matched tied and loose-housed herds increased with the age of the cowsheds, but without presenting any figures. The authors thought this may have been due to a need for a certain period of time for the cows to adapt to new housing conditions before the advantages of a loose-housing system could appear. The described effect was not confirmed by this study.

SLB herds had higher incidences of all clinical diseases and a higher prevalence of high MSCCs than *SRB* herds. This is in accordance with several other studies (*e.g.* Andersson and Lundström, 1981; Bendixen *et al.*, 1988a; 1988b; Bergsten, 1994; Swedish Dairy Assoc., 2001b). Large herds (>70 cows) tended to have more foot and leg disorders but fewer cases of clinical mastitis and teat injury than smaller herds. Confounding by housing system and transition phase probably contributed to these associations. Rowlands *et al.* (1983) found lower incidence rates of interdigital necrobacillosis but higher rates of sole ulcer in large herds. Barkema *et al.* (1998a) and Ekman (1998) found herds with high bulk MSCCs to be larger than herds with low cell counts. Alban *et al.* (1995) found a higher incidence of interdigital phlegmon in primiparous than in multiparous cows, which the present data confirm. Higher incidences of mastitis and teat lesions, and higher MSCCs in older cows than in younger have been described by *e.g.* Honkanen-Buzalski *et al.* (1981), Kennedy *et al.* (1982), Bendixen *et al.* (1988a and 1988b) and the Swedish Dairy Association (2001b). In this study, no simple association was found between herd average parity and udder health, which may indicate that the variable representing parity did not reflect the age structure very well. There were strong positive relationships between the number of cows having calved recently and all clinical disease traits, in accordance with Bendixen *et al.* (1988a; 1988b), Alban *et al.* (1995) and Vaarst *et al.* (1998). There was also a clear negative relationship between recent calving and the prevalence of high MSCCs, in accordance with Honkanen-Buzalski *et al.* (1981) and Kennedy *et al.* (1982).

The relationship between MSCCs and mastitis is not straightforward. As mentioned above, elevated milk cell counts are regarded as an indication of subclinical mastitis (Andersson, 1988; Reneau, 1986). However, a substantial decrease in the mean bulk MSCC in the Netherlands between 1985 and 1995, due to a regulatory limit for bulk milk cell counts, was not accompanied by any reduced incidence of clinical mastitis (Barkema *et al.*, 1998b). Higher incidence rates of clinical mastitis have in fact been found in herds with low (<150,000 cells/ml) bulk MSCCs than in herds with higher cell counts (Miltenburg *et al.*, 1996; Elbers *et al.*, 1998). According to Barkema *et al.* (1998b), the incidence of clinical mastitis is not related to bulk MSCCs, although the variation in clinical mastitis incidence increased as cell counts decreased. Barkema *et al.* (1999) showed that the pathogen-specific incidence rate of clinical mastitis from *E. coli* infection can decrease and the incidence of clinical mastitis caused by *Staph. aureus* and *Streptococcus dysgalactiae* can increase with higher bulk MSCCs, although there is no significant overall association for all cases of clinical mastitis.

Health disturbances during and after rebuilding may lead to depressed productive and reproductive performance, which might be viewed as growth sacrifices in the economical terminology of Olsson (1988). The present thesis was not aimed at investigating such sacrifices. Nevertheless, the described negative effects on foot and leg health when changing from tie-stalls to cubicles are an example of transitory growth sacrifices, although not estimated in economical terms.

Synthesis

Experimental and observational methods

In this thesis, both observational and experimental methods are applied. In particular, the animal health effects of electric cow-trainers are discussed in light of research based on both approaches.

It is generally agreed that stronger statistical inferences can be made from experiments than from observational studies (*e.g.* Altman, 1991). The ideal experiment would create sets of circumstances across which only one factor affecting the outcome of interest would vary (Rothman and Greenland, 1998). The treatments must be assigned to the subjects according to a formal study protocol. Alternating assignments to treatment groups (*e.g.* every second cow on a list to each of two groups, as in Paper III) may be called quasi-randomization. However, what is often forgotten is that the experiment, by definition, is conducted under more or less artificial conditions, which may render its results less useful, no matter how valid these may be in the current experimental setting. Perhaps even more importantly, experiments easily overlook the existance of important biological interactions between extraneous factors and the exposure factor. In the study of risk factors for health and production disturbances on the dairy herd level, interactions are very likely to occur. This is probably reflected by the difficulties to find a good set of independant variables to include in models of the occurrence of production diseases, experienced by many epidemiological researchers (Dohoo *et al.*, 1996).

Nevertheless, even in a controlled trial, important interactions can be considered in the statistical analysis. For instance, in the experiment in Paper III, data regarding cleanliness and foot health were modelled by multiple regression and interactions between type of flooring and other predictors were tested. Indeed, one important interaction was found, between flooring and type of stall divider in the analysis of foot cleanliness. This interaction would not have been discovered in a more straightforward analysis, comparing the two floor groups by *e.g.* Student's *t*-test.

Consequently, as illustrated by the work presented in this thesis, experiments and observational studies play complementary roles in veterinary research. In experiments, reality is simplified and only one or a few factors are allowed to influence the outcome, resulting in highly valid results, internally. The scientific process is then restricted to the testing of relatively simple hypotheses (*e.g.* Papers II and III). In observational studies, on the other hand, the investigator tries to interpret reality as it is, demanding more emphasis on a correct selection of study subjects and statistical analysis, but increasing the possibilities to discover complex relationships between risk factors, and probably generating more generalizable results (Papers I and IV). It may be argued that observational studies are essential for the abstraction of a scientific hypothesis beyond time and place that generalization implies (Schwartz *et al.*, 1999). Thus, both scientific approaches are needed to increase our knowledge about production diseases and highlight different aspects of animal health problems.

The issue of ECT effects illustrates the relationship between experimental and observational methods. Apparent contradictory results from ECT research have puzzled farmers, advisors and decision makers for a long time. Due to the design of the cohort study in Paper I, it was not possible to study crucial aspects of foot health. Likewise, the experiments regarding ECTs and foot health presented by other researchers did not allow for an evaluation of a possible influence on other health traits, reproductive performance or culling. This seems to leave everybody deciding whether or not improved foot health is more important than maintained udder health and fertility. To tell if ECTs should be allowed or not, it is not enough to scrutinize the scientific techniques applied and generalize the results to present and future dairy production, interpreting the conflicting results in proper view of the applied study designs. We must also consider estimated effect levels, probabilities, and the consequences for animal well-being, public opinion and production economy. Finally, there may be other deleterious ECT effects, *e.g.* related to stress, that have not even been discovered yet. In the end, the answer may be a matter of what set of values we apply.

Causality

Animal health and production disturbances are often mediated through behavioural changes, as illustrated by the following well-established causal chains:

Faulty tie-stall design → abnormal lying down → tramped teats → mastitis
Limited space in alleys → agonistic encounters → accidents → injuries
Defective scraped alley flooring → poor alley hygiene → foot lesions
Defective slatted alley flooring → abnormal walking → foot lesions
Faulty cubicle design → much time spent standing → laminitis

Naturally, causal chains may also lead to improved health. In this thesis, the following relationships that include animal behaviour have been suggested regarding the effect of electric cow-trainers:

ECT → hampered estrous behaviour → poor reproductive performance
ECT → reduced feed intake → ketosis
ECT → reduced freedom of space → stress → mastitis
ECT → disturbed lying-down behaviour → tramped teats → mastitis
ECT → changed eliminative behaviour → cleaner stalls → less heel erosion

Due to the mediating role of the animals' behaviour, behavioural measures have been used as indicators of the detrimental or wholesome effects of housing and management factors (*e.g.* Wierenga and Peterse, 1987; Hultgren, 1991), regardless of the importance of the behavioural expressions themselves. Behavioural changes are usually early signs of discomfort. It has clearly been shown that behavioural studies contribute significantly to our knowledge about the influence of housing and management factors on animal health and production (Algers and Jensen, 1991; Sandøe and Hurnik, 1996; Wechsler *et al.*, 1997; Hörning, 2000). In fact, the study of cow behaviour in Paper II supports the idea that the rubber slat system does not increase the risk of diseases caused by abnormal resting, lying-down and rising behaviour, such as many cases of tramped teats and teat-tramp-induced mastitis, although such health effects were difficult to study directly in this experimental setup.

During the second half of the last century, risk factor analysis was assigned much attention in epidemiologic research. The concept of 'black box epidemiology' was used by critics as a metaphor to connote that the associations between risk factors and diseases were studied without regard to the causal linkages between them (Skrabanek, 1994; Schwartz *et al.*, 1999). Morgenstern (1995), Susser and Susser (1996), Diez-Roux (1998), Schwartz *et al.* (1999) and others encouraged thinking about causes of diseases at multiple levels of organization, within the historical context of both societies and individuals. Diez-Roux (2000) reviewed the rationale for using multilevel analysis in ecologic epidemiology, and discussed its potentials and limitations.

Although the debate on ecologic epidemiology and multilevel approaches had its roots in concerns for the scientific foundations of public health, it also pertained to veterinary epidemiology. However, the structure of farm animal populations is different from human population structures in a number of ways. Farm animals in general are more alike, because of a narrower basis for breeding. They are normally grouped in farms or herds, with common housing, management and feeding conditions, while the differences between herds may be greater. Finally, on a regional or national level, there are cultural, social and economical factors common to all herds. Since long ago, veterinary researchers are aware of – and troubled by – the impact of herd-level factors on disease occurrence. Not until recently, as a result of the public health debate, have analytical tools become available to handle these multilevel relationships adequately.

Applying the multilevel perspective to the ECT issue, it may be seen that 'the use of ECTs' is not a univocally defined exposure factor, but may entail several aspects of exposure to a highly varying degree. Using the concept of causal chains, the (cultural, technological, social, *etc.*) animal husbandry context in which ECTs are used, probably affects their influence on subsequent links in the chain, *e.g.*:

Prohibition → limited and sometimes incorrect ECT use →
Public opinion against ECTs → restricted and correct ECT use →
Veterinary supervision → restricted and correct ECT use →
Competent farmers → correct ECT use →
Rubber mats → ECT shocks perceived as weaker →
Wet or dirty stalls → ECT shocks perceived as stronger →
ECT technologically improved → well-functioning ECTs →

As discussed in the introductory section, there is a conflict between demands for a clean tie-stall and the cow's freedom of movement. Any tie-stall design is a compromise between these two. ECTs may be viewed as a means to improve the hygienic conditions of the stall at the price of restricted cow movements.

In Paper IV, several cow-level factors were summarized into aggregate measures at the herd level. Apparently, the inclusion of mean parity in the statistical models did not account very well for the influence of the cows' age on disease occurrence in the herds. This illustrates one of the difficulties encountered in multilevel studies.

Practical implications

Clearly, many recommended and adopted housing solutions have been compromises. Veterinary research should supply knowledge to facilitate balancing contradictory demands in livestock housing design and stimulate the development of new housing and management solutions. Farm buildings are long-range investments and mistakes in the design may be disastrous. Unfortunately, the consequences of a new trend in housing design or a certain type of equipment are sometimes unforeseeable. Farmers who have adopted a recommended new system, more or less willingly, are stuck with it, in some cases resulting in animal suffering, economic losses and even personal tragedies.

Along with the increased public concern for animal welfare and food quality, and a far-reaching animal welfare legislation, there is increasing pressure on the dairy industry to produce without causing discomfort to the animals or reducing the quality of the products. In several countries, dairy cattle are traditionally kept in tie-stalls. A housing system that prevents the animals from walking, moving without restrictions of the equipment, or interacting with herdmates during most of the year should be seriously questionned – not only in organic production. However, a transition from tie-stalls to loose housing will not be without problems. As shown by this thesis and other research, there may be important negative transitory and long-lasting effects on animal health when changing from *e.g.* tie-stalls to cubicles and, given the prevailing conditions in existing dairy installations, foot lesions are much more common in cubicle houses than in tie-stall barns. These problems remain to be solved to limit the negative effects of such a transition.

Therefore, if the ongoing transition to loose housing is to be speeded up by political decisions and legislation, sufficient time should be given farmers to plan and build new facilities. Legal measures should be preceded by a careful assessment of known effects of different housing systems and of the transition itself on animal health, well-being and productive performance. In the development of cubicle systems, designs that are likely to affect hygiene, cow comfort, foot/leg and udder health should be considered carefully. Farmers that change housing system from tie-stalls to loose housing should be aware of expected negative effects on the cows' foot and leg health.

Alternatives to the electric cow-trainer should be sought, to improve hygienic conditions in tie-stalls without compromising the health of and decreasing the welfare of the cows. The use of electric cow-trainers cannot be justified solely by scientific evidence, since there are both positive and negative effects on animal health and well-being. Possibly, a restricted use of the device under supervision of *e.g.* veterinarians, might mitigate its negative health effects.

When rebuilding tie-stalls, rubber slatted flooring may be used to improve the hygiene, without serious negative effects on animal behaviour and foot health. In contrast to tie-stalls, where contradictory demands for lying and eating have to be considered, the usefulness of the rubber slat system in cubicles and feed stalls is probably limited, because these are easier to design optimally.

The possibilities to create a national computerized database for housing conditions in Swedish dairy herds should be investigated, making use of *e.g.* Norwegian experiences. To be useful for veterinary science, such a database should contain information about building standard, type of flooring and stall design (long-term parameters), but preferably also equipment for dung disposal, feeding and milking (medium-term), and important management routines, bedding quality and hygiene (short-term). Stored data should frequently be revised by competent personnel. The database could be combined with the official recording systems for milk production and animal diseases, *e.g.* to describe housing trends and identify animal health risk factors.

Further research is suggested regarding possible effects of rubber slatted flooring systems on the occurrence of teat injuries and mastitis, using observational study methods. It is also important to further identify major risk factors for foot/leg and udder health disturbances in loose housing, and especially in connection with a transition from tie-stall housing. For this purpose, both observational and experimental methods would be appropriate. To be able to estimate costs of impaired animal health, relationships between diseases should be further investigated, *e.g.* the importance of foot health on the occurrence of teat injuries and mastitis, again making use of both observational and experimental methods, as well as the influence of diseases on productive and reproductive performance.

Conclusions

Exposure to electric cow-trainers increases the risk of silent heat, clinical mastitis and ketosis, and changes silent heat from a neutral disease with respect to culling to a major risk factor. Cow-trainers increase the general negative effect of diseases on the cows' reproductive performance and risk of culling.

Cows in tie-stalls equipped with rubber slatted flooring in the rear part, an ethyl-vinyl-acetate mat in the front part and small amounts of wood shavings as bedding, lie down and rise normally, and without an increased risk of slipping. In comparison with traditional tie-stalls with a solid floor, standard rubber mats and a thick bedding of chopped straw, the rubber slat system improves the cows' ability to lie down comfortably, increases the cleanliness of their hind parts, and decreases the prevalences of dermatitis and heel horn erosion in their hind feet. There seems to be a preference for lying on a solid floor instead of rubber slats.

There are significant increases in the incidence of veterinary-treated foot and leg disorders when changing from tie-stalls to cubicles, and decreases in the incidence of clinical mastitis and teat injuries when changing from tie-stalls to cubicles or straw-yard systems. Effects on foot and leg health generally last for less than 18 months after building finish, while effects on udder health often persist for more than 18 months. Reductions in the incidence of clinical mastitis are not reflected by any major changes in milk somatic cell counts. Beyond 18 months after rebuilding, herds that shift from long-stalls to short-stalls have less foot and leg lesions than those remaining in long-stalls.

Sammanfattning

Hur lantbrukets djur inhyses påverkar i hög grad deras beteende och hälsotillstånd. Syftet med föreliggande avhandling är att belysa inverkan av några viktiga inhysningsfaktorer på förekomsten av produktionssjukdomar hos mjölkkor och att klargöra relationen mellan experimentella och epidemiologiska forskningsmetoder i studier av sjukdomsmönster i mjölkkobesättningar. Betydelsen av att djurens hålls rena betonas och konsekvenserna för deras beteende, renhet, hälsa och välbefinnande av olika inredningar för bundna kor diskuteras. Särskilt behandlas inverkan av elektriska kodressörer på djurens hälsa och välfärd, i ljuset av denna avhandling och tidigare forskning. Betydelsefulla effekter på kornas fot-, ben- och juverhälsa i samband med en övergång från lång- eller kortbås till lösdrift diskuteras också.

Effekter av elektriska kodressörer på klinisk sjuklighet, fruktsamhet och risk för utslagning studerades genom att uppgifter från 33 svenska kodressörbesättningar jämfördes med historiska och samtida kontroller i 117 besättningar utan kodressörer (Delarbete I). Studien omfattade 10264 laktationer hos SRB-kor och 5461 laktationer hos SLB-kor. Exponering för kodressörer ökade risken för brunstsvaghet, klinisk mastit och acetonemi, och gjorde brunstsvaghet till en betydelsefull riskfaktor för utslagning. Kodressörerna ökade den allmänt negativa effekten av sjukdomar på kornas fruktsamhet och på risken för utslagning. I kodressörbesättningar orsakade brunstsvaghet, äggstockscysta och en kombination av två eller flera sjukdomar den största förlängningen av intervallet från kalvning till sista insemination (57-59 dagar), medan effekten var mindre i besättningar utan kodressörer (43-53 dagars förlängt intervall). Kvarbliven efterbörd, akut livmoderinflammation, äggstockscysta, klinisk mastit och en kombination av två eller flera sjukdomar fördubblade risken för utslagning och effekten var störst i besättningar där kodressörer användes.

Inverkan av en båstyp med gödseldränerande gummispaltgolv på bundna kors beteende, renhet och fothälsa studerades i ett kontrollerat experiment under två stallsäsonger i en försöksbesättning med 42 kor i långbås (Delarbete II och III). På hälften av båsplatserna ersattes de bakersta 0,74 m av båsgolvet med nio gummiklädda, 53 mm breda stavar, åtskilda av 29 mm vida spaltöppningar. Bås med gummispalt försågs med en 20 mm tjock båspallsmatta (etyl-vinyl-acetat) i sin främre del, ströad med en mindre mängd (0,7 kg) kutterspån dagligen. Bås med helt golv hade ordinära gummimattor och ströades med en större mängd (3 kg) hackad halm dagligen. Korna i bås med gummispaltgolv hade lättare för att lägga sig än korna på helt golv. De reste sig normalt och utan ökad tendens att halka. Studien antydde dock att korna föredrog det hela golvet framför spaltgolvet när de låg. Korna på gummispaltgolv var mycket renare än korna på helt golv. Vid klövverkning var prevalensen av hygienrelaterade fotskador (eksem och klövröta) på bakfötterna 4-11 gånger lägre på gummispaltgolvet än i bås med helt golv. Klövhälsoeffekterna kan helt eller delvis förklaras av den förbättrade renheten på gummispaltgolv. Studien ger inte några belägg för att gummispaltgolv skulle öka risken för sådana sjukdomar som kan orsakas av ett onormalt vilo-, läggnings- eller resningsbeteende, t ex spentramp och mastit till följd av spentramp. Gummispaltgolv är sannolikt användbart i alla slags bås för kor, men kan förväntas ge störst effekt på djurens renhet i lång- och kortbås.

I syfte att studera effekterna av en övergång från ett stallsystem till ett annat på klöv-, ben- och juverhälsa, utnyttjades månatliga uppgifter om sjukdomsförekomst i 194 svenska mjölkkobesättningar (Delarbete IV). En 3-5 gånger ökad förekomst av veterinärbehandlade klöv- och benskador påvisades upp till 18 månader efter byte från kort- eller långbås till lösdrift med liggbås. Incidensen av klinisk mastit och spenskador minskade efter byte från ett system med bundna kor till lösdrift med liggbås eller ströbädd. Minskningen var märkbar även senare än 18 månader efter ombyggnad, men åtföljdes inte av några tydligt sänkta celltal i mjölken. Senare än 18 månader efter ombyggnad hade besättningar som bytte från lång- till kortbås en tredjedel så många fall av fot- och benskador som besättningar som fortfarande hölls i långbås.

Avhandlingens övergripande slutsatser är **att** elektriska kodressörer har negativa effekter på djurhälsan och ökar det negativa inflytandet av sjukdomar på kornas fruktsamhet och risk för utslagning, **att** gummispaltgolv underlättar för bundna kor att lägga och resa sig i båset, förbättrar deras renhet och minskar förekomsten av klövsjukdomar, samt **att** en övergång från lång- eller kortbås till lösdrift ökar förekomsten av veterinärbehandlade klöv- och benlidanden tillfälligt, men minskar frekvensen klinisk mastit och spentramp mer långvarigt.

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