Housing can deeply affect the welfare of dairy cows and consequently their performance. Actually, free stall barns (FS) represent the most widespread housing system in intensive dairy farms. However, recent findings showed that this system can severely compromise animal welfare, especially as regards feet and leg health. Cultivated pack barns (CPB), known in many countries as compost barns, are relatively new housing option for dairy cows that seems to offer improved cow comfort. The CPB system has spread in Italy since 2006 but scientific knowledge about it is still sparse. The primary objective of this work was to provide management and design recommendations for Italian CPB. To do this, an extensive review of literature concerning CPB systems was performed. Existing CPB in Italy were surveyed and their performance was compared with FS. Moreover, the thermal performance of greenhouse-type structure, which appeared a viable alternative for CPB construction, was investigated. Results showed that, if properly managed, CPB can represent an effective solution for housing dairy cows also in Italy. Compared with FS, CPB improved cow's longevity, indicating better cow comfort and health. Producers indeed identified animal welfare as the main benefit of CPB and overall they appeared to be very satisfied. Nevertheless, concerns about the cost of bedding suggested that pack management and barn characteristics have not yet been optimized. Italian producers with CPB allotted a very low space per cow (6.8 m^2/cow), which has confirmed to be a key factor for this kind of housing system. A model was implemented to identify the optimal space allowance in Italian CPB. Outcomes showed that a space per cow of 14.6 m^2/cow would allow to minimize running costs. On the basis of information collected the design of an optimal CPB within the Italian context was proposed and discussed.

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Lorenzo Leso Performance and design of an alternative housing system for dairy cows

PERFORMANCE AND DESIGN OF AN ALTERNATIVE HOUSING SYSTEM FOR DAIRY COWS

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ABSTRACT OF THESIS

PERFORMANCE AND DESIGN OF AN ALTERNATIVE HOUSING SYSTEM FOR DAIRY COWS

Housing can deeply affect the welfare of dairy cows and consequently their performance. Actually, free stall barns (FS) represent the most widespread housing system in intensive dairy farms. However, recent findings showed that this system can severely compromise animal welfare, especially as regards feet and leg health. Cultivated pack barns (CPB), known in many countries as compost barns, are relatively new housing option for dairy cows that seems to offer improved cow comfort. The CPB system has spread in Italy since 2006 but scientific knowledge about it is still sparse. The primary objective of this work was to provide management and design recommendations for Italian CPB. To do this, an extensive review of literature concerning CPB systems was performed. Existing CPB in Italy were surveyed and their performance was compared with FS. Moreover, the thermal performance of greenhouse-type structure, which appeared a viable alternative for CPB construction, was investigated. Results showed that, if properly managed, CPB can represent an effective solution for housing dairy cows also in Italy. Compared with FS, CPB improved cow's longevity, indicating better cow comfort and health. Producers indeed identified animal welfare as the main benefit of CPB and overall they appeared to be very satisfied. Nevertheless, concerns about the cost of bedding suggested that pack management and barn characteristics have not yet been optimized. Italian producers with CPB allotted a very low space per cow (6.8 m^2/cow), which has confirmed to be a key factor for this kind of housing system. A model was implemented to identify the optimal space allowance in Italian CPB. Outcomes showed that a space per cow of 14.6 m^2/cow would allow to minimize running costs. On the basis of information collected the design of an optimal CPB within the Italian context was proposed and discussed.

KEYWORDS: cultivated pack barns, compost bedded pack barns, cow welfare, management, design

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CHAPTER ONE: REVIEW OF LITERATURE

INTRODUCTION

Housing system can affect dairy cow's welfare and performance and have a major influence on the ecological footprint and the consumers' perception of dairy farming. Since shifting from tie-stall to loose housing, many different systems have been developed. The most widespread solutions are free stall barns (FS) and straw yard barns (SY). Although both of them have advantages and disadvantages, in the last few decades FS have been established as the standard housing solution for dairy cows. Many studies have been carried out on this housing system allowing substantial developments. However, in recent years, research demonstrated that free stall housing may severely compromise animal welfare. Together with this, consumers' concerns about the conditions of dairy cows in intensive systems have fostered the interest toward alternative housing solutions. Cultivated pack barns (CPB), also known as compost dairy barns, are a relatively new housing system that appears to offer excellent cow comfort and minimizes the risks traditionally associated with straw yards or other conventional deep bedded packs. This review of literature aims at describing FS, SY and CPB for dairy cows with a special focus on management and animal welfare.

AN ALTERNATIVE TO FREE STALLS AND STRAW YARDS

A dairyman from Washington (USA), Adolph Oien, is credited with developing the FS concept when in 1959 he installed a series of individual stalls in a loose housing shed (Bickert and Light, 1982). Compared to bedded packs, free stalls required less bedding and cows stayed cleaner. Some years later, developments in barn design and the adoption of mechanical systems to remove manure allowed a sensible reduction in the labor needed. These advantages led to a fast spread of this housing system, which has been widely adopted all over the world, especially for lactating cows. The leading concept of free stall housing is to keep manure and urine separated from the surfaces where cows lie. As a matter of fact, in FS there is a physical distinction between walk and feed alleys and the resting area that, in turn, consists of cubicles. This allows to keep cows cleaner and, since most of the excreta have not to be absorbed by the bedding, it also reduces the amount of bedding materials needed (Bickert and Light, 1982).

Free stalls are designed to provide a comfortable lying context for the cow but, at the same time, they have to minimize stall soiling by forcing the cow to defecate and urinate in the alley outside of the stall (Tucker et al., 2005). Stall size and configuration have to be set up taking into account these two issues since changes in stall design that result in improvements in cow comfort come at the expense of cow and stall cleanliness (Bernardi et al., 2009; Fregonesi et al., 2009). Also the type of bedding used in free stalls can modify comfort and hygiene level. Free stalls can be either deep bedded or provided with synthetic mattresses.

A wide range of different materials can be used in bedded free stalls. The most commonly used materials are sand, straw, sawdust and recycled manure solids. Deep bedded free stalls generally provide a good comfort level but they are labor intensive and require relatively large amount of bedding materials to maintain adequate hygienic conditions (Bewley et al., 2001). Synthetic mattresses have been developed to reduce labor and bedding needs but in many situations their employment results in reduced lying comfort and increased hock lesions and lameness (Cook et al., 2004; Fulwider et al., 2007).

In FS manure and urine are deposited on the bare floor of the feeding area or in the alleys between cubicles. To avoid manure build up on these surfaces, which negatively affects hoof's health and cow's hygiene, manure scrapers, washing systems or slatted floors have to be adopted. Regardless of the cleaning system employed, the main material used for flooring is concrete, since it is durable, easy to clean and reasonably priced (Albright, 1995). Nevertheless, concrete floor is hard and slippery, especially if it's not adequately grooved or worn, and thus poses serious challenges in terms of animal welfare.

Covering the floor with rubber mats is a quite common solution to improve its physical characteristics and, in turn, claw health (Vanegas, 2006; Fjeldaas et al., 2011; Eicher et al., 2013). However, rubber mats are expensive and, due to their smooth surface, may cause a reduction in claw wear resulting in claw overgrowth

(Platz et al., 2007). Another problem associated with rubber flooring is the increased number of cows resting in the alleys (Platz et al., 2008). This results in soiling, especially of the udder, and increase the risk of infections such as mastitis.

Although there are several solutions to improve animal welfare in FS, this kind of housing system has been developed primarily to reduce labor and bedding consumption and thus create a completely different environment from that is optimal for cows: the pasture. A recent research commissioned from the European Commission (EFSA, 2009) shows that housing system is a major factor influencing animal welfare and that free stall housing increases health related risks, especially as regards leg and locomotion. Lameness is largely recognized as one of the most important problems in modern dairy farms (Kester et al., 2014).

Disturbed claw health is a source of suffering for the cows (Webster, 1995), because the disorder is usually long term and painful (Alban, 1995). In FS, prevalence of claw lesions was estimated to be 70 to 80% (Manske et al., 2002; Somers et al., 2003). Actual lameness rates have been stated as not acceptable from an animal welfare point of view and besides that they give rise to a growing concern about the conditions of cows in intensive farms (Farm Animal Welfare Council, 1997; Kester et al., 2014).

In FS, concrete flooring is a major cause of claw disorders, especially when is not adequately clean (Somers et al., 2005; Dippel et al., 2009; Telezhenko et al., 2009; Kester et al., 2014). Somers et al. (2003) found that, in FS, 80% of cows exposed to concrete flooring had claw disorders at clinical or subclinical level with many cows having two diseases at the same time. Free stall's characteristics can also affect claw health indirectly. Uncomfortable stalls may modify the normal behavior of cows resulting in reduced lying time (Fregonesi et al., 2009; Norring et al., 2008; Ito et al., 2010; Gomez and Cook, 2010; Barbari et al., 2012). This increases the risk of lesions and infections since cows spend more time standing (or walking) on concrete (Fulwider et al., 2007; Fregonesi et al, 2007; Kester et al., 2014).

Furthermore, behavioral modifications induced by inadequate housing penalize both productive and reproductive performance. Since lying time is positively related to rumination (Shirmann et al., 2012), low comfort in resting areas may result in reduced milk production. On slippery floors, cows feel unsafe and are not really able to display their normal behavior (Telezhenko and Bergsten, 2005; Frankena et al., 2009). Limited estrus behavior and reduced activity have been observed in cows housed on concrete floors making heat detection more difficult and impairing fertility (López-Gatius et al., 2005; López-Gatius, 2012).

Bedded pack barns have been developed during the mid-1950s (Bickert and Light, 1982). In this kind of barns cows are provided with an open pack resting area rather than individual stalls. The SY housing systems is believed to provide better comfort than FS. In a recent review article, Kester et al. (2014) reported that the presence of hock lesions is strongly related to time spent lying on abrasive surfaces, prolonged high local pressure or friction of the hock on hard surfaces, and collisions of the hock with cubicle fittings. Prevalence of hock lesions is positively correlated with lameness rate (Haskell et al., 2006; Kester et al., 2014). In SY, the soft bedded surface on which cows lie, stand and walk results in less hoof damage and lameness compared with FS (Somers et al., 2003; Haskell et al., 2006; Frankena et al., 2009).

Cows housed in SY also express different behavior than those in FS. Fregonesi et al. (2009) found that when offered the choice, cows spent more time in an open pack than in an equivalent free stall. Cows also spend more time lying and standing with all 4 hooves in a bedded open pack than in the stalls. Furthermore, when provided access to an open area, cows spent less time standing outside of the lying area and perching with the front 2 hooves in the lying area, both of which are behaviors associated with increased risk of lameness. Studies on cow's time budget showed that cows in SY have greater lying time, ruminating time and synchronization of lying behavior than those in FS (Fregonesi and Leaver, 2001).

On the other hand, SY may hinder cow's welfare through increased risk of intramammary infection. Maintaining adequate cow cleanliness can be a major issue in SY. Cows in SY have found to be dirtier than those in FS (Fregonesi and Leaver, 2001) and thus negatively affected udder health. As a matter of fact, Fregonesi and Leaver (2001) found that both somatic cell count and incidence of clinical mastitis were significantly higher in SY than in FS. Peeler et al. (2000) reported that housing lactating cows in SY is a significant risk factors associated with the incidence of clinical mastitis.

Free stalls and SY have been widely used for more than fifty years although, in the last decades, FS has established as the standard housing solution for lactating cows. From an animal welfare stand point, the main advantages of FS appear to be cow cleanliness and reduced mastitis compared to SY. However, FS housing poses several challenges in terms of claw health and cow's behavior. In the last years, animal welfare has become one of the most important issues facing the dairy industry because it affects profitability and because consumers demand for animal friendly systems has risen and will likely continue to increase, especially in developed countries. As a result, the interest toward alternative housing systems has been fostered.

CULTIVATED PACK BARNS

Cultivated pack barns (CBP) for dairy cows, also known as compost dairy barns, are relatively new housing systems that seem to offer improved cow welfare. In this type of barns cows are provided with an open bedded pack area for resting and walking rather than individual stalls and concrete alleys. In this type of barns, cows are provided with an open bedded area rather than individual stalls. Cultivated pack refers to a mixture of feces and urine produced by the cows and organic beddings. In CPB the most commonly used bedding materials are sawdust, wood chips and compost from organic wastes (Barberg et al., 2007a; Galama et al., 2011). Unlike conventional straw-bedded yards, the whole pack is cultivated once or twice daily (Klaas and Bjerg, 2011). If properly managed, CPB provide a healthy, dry and comfortable surface on which cows can lie, stand and walk.

In a review article, Klaas and Bjerg (2011) defined compost barns as housing systems where a deep-bedded pack is aerated to enhance heat production and microbial activity and thus increases the evaporation of water. Experiences with CPB are reported in literature from the US, Israel, South Korea, the Netherlands, Austria, Spain and Italy (Barberg et al., 2007a; Vighi et al., 2009; Klaas et al., 2010; Galama et al., 2011, Black et al., 2013; Ofner-Schröck et al., 2013; Astiz et al., 2014).

Although all types of CBP developed in different countries have some similar characteristics, noticeable differences can be found among them. As a matter of fact, an open bedded area and frequent pack cultivation appear to be the only features that different CPB around the world have in common.

Different types of cultivated pack barns

First peer-reviewed papers regarding CPB are due to a research group from the University of Minnesota (Barberg et al., 2007a and 2007b; Endres and Barberg, 2007, Janni et al., 2007). Barberg et al. (2007b) claimed that first CPB was built in Minnesota in 2001 but Wagner (2002) reported that Virginia dairy farmers first developed CPB concept to improve cow comfort, increase longevity and to reduce initial barn cost. First CPB in Israel was developed in 2006 and, since then, the system spread rapidly. Actually CPB is the most common housing system in Israel even though scientific information about it is still sparse. In this system stirring occur once or twice daily but no beddings are needed and the pack is made up of just dried manure (Klaas et al., 2010). American and Israeli CPB concepts are quite different and represent the bases on which other similar systems have been developed in Europe.

Management and design of American CPB focus on heat production in the pack (Janni et al., 2007). Since in this type of barns a process similar to composting occurs (in the pack), they are better known as compost dairy barns. In this type of CPB, the most important issue is to maintain adequate chemical and physical characteristics in the substrate in order to promote microbial activity (Black et al., 2013). As for all types of bedded pack, cow density is a key factor. For American CPB, Janni et al. (2007) recommended a minimum of 7.4 m^2/cow for a 540-kg Holstein cow or 6.0 m^2/cow for a 410-kg Jersey cow. In a survey including 44 CPB in Kentucky, Black et al. (2013) found that producers allotted 9.0 ± 2.2 m^2 bedded pack per cow but, when adjusted for pasture access, pack density was 12.0 ± 7.6 m^2/cow.

In American CPB, pack should to be cultivated twice daily to maintain aerobic conditions (Janni et al., 2007). The most common bedding materials are sawdust and wood shavings (Barberg et al., 2007a; Black et al., 2013). However, Shane et al. (2010) tested a wide variety of different substrates founding that almost any kind of organic material would work in CPB if proper bedding management is applied on a consistent basis. They concluded that ideal bedding material for CPB should be dry, processed to less than 2.5 cm long, offer structural integrity, and have good water absorption and holding capacity.

In the last few years, other CPB systems similar to the American compost barns have been developed in Europe. With the aim of enhancing the composting process, automatic systems that blow (or suck) air into the pack have been employed in some Dutch dairies (Galama et al., 2011). Aeration systems mainly consist in perforated tubes that are installed in the concrete floor below the pack and are connected to an external air pump. In this kind of barns the pack is stirred mostly once daily and the main bedding material used is wood chips (Galama, 2014). To keep the pack sufficiently dry in the humid Dutch weather and limit the amount of wood chips needed, a pack density of 15 m^2/cow is recommended even though, with aeration systems and optimal management, 12 m^2/cow appear to be adequate (Galama, 2014). In the Netherlands, this type of CPB is known with the name composting bedded pack.

A Dutch farmer, Mark Havermans, developed another CPB system that is quite similar to that employed in Israel and it is not based on the production of heat into the pack. The main material used in this kind of CPB is compost from organic wastes (Galama, 2014). For this reason this housing system is known in the Netherlands as compost bedded pack (Galama et al., 2011) although differences with the American CPB are substantial. The pack is stirred once daily and the recommended pack density in this type of CPB ranges from 15 to 20 m^2/cow in barns provided with scraped or slatted feeding alley and up to 30 m^2/cow in systems without concrete alleys (Klaas and Bjerg, 2011). Climate in the Netherlands is completely different to that in Israel. Despite that, Klaas et al. (2010) reported similar pack density in Israeli CPB. Other CPB systems have been developed in Austria, Spain, Italy, South Korea and Brazil but little or no information about them is available in scientific literature.

Pack management

Regardless of the type of CPB, pack management aim at providing a hygienic and comfortable surface on which cows can rest, stand and walk. Besides the type of bedding, the most important characteristic of the pack is certainly the moisture content. Moisture level of the pack can affect cow cleanliness and ease of movement (Klaas and Bjerg, 2011). The optimal moisture level for a cultivated pack ranges between 40 and 65% (Janni et al., 2007). Wetter bedding may adhere to the cows resulting in dirty animals and consequently in an increased risk of mastitis and longer time for teat preparation at milking (Black et al., 2013). Some farmers also noticed that when the pack is too wet cows appear to have some difficulties in walking on it and prefer to walk and stand on concrete areas (Havermans and Hartman, personal communication, 2013). On the other hand too dry pack may result in increased emission of dust. Moreover, in an experimental CPB with compost bedding in Italy some cows had brief but severe lameness during the summer period, when the pack was particularly dry (Bima, personal communication, 2014).

In order to keep moisture level in the optimal range, water produced by the animals through excreta has to be absorbed or evaporated. Obviously, absorbing water in excess requires dry bedding materials and thus increases costs. To limit the amount of bedding needed, evaporation of water from the pack have to be fostered. In an ideal CPB, the balance between the water added with cows' excreta and the water evaporated is constantly neutral. This allows to maintain adequate pack conditions without any bedding.

A Holstein cow yielding 35 liters of milk per day produces approximately 65 kg of manure and urine per day containing 56.5 kg of water (ASAE, 2005). Therefore, to keep the moisture level of the pack at 50% without additional beddings, 48 liters of water have to be removed. Dutch researchers argued that in CPB about 50% of manure and urine is deposited in the feeding area (Galama et al., 2011; de Boer, 2014). Therefore, in a CPB provided with a scraped or slatted feeding alley, to avoid any external source of bedding, about 24 liters of water per cow and per day have to be evaporated or absorbed from the pack.

Since evaporation occurs mainly on the surface of the bedding, the water balance of the pack and, in turn, bedding consumption strictly depends on the space allotment per cow. For this reason many authors consider pack density as a key factor in CPB (Klaas and Bjerg, 2011). Recommended pack densities for CPB systems differ widely and appear to be based on practical experiences in existing barns. No standardized methods are available to determine the optimal pack density in CPB. In all CBP systems, bedded area space per cow strictly depends on the evaporation of water from the pack. Required space allotment decreases with increasing drying rate. However, determining drying rate of a cultivated bedded pack poses some challenges. Several factors affect evaporation and, since environmental conditions have a great influence, drying rate is affected by the climate and can have wide variations throughout the year. Little is still known about evaporation in CPB and no published studies measured pack drying rate directly in this kind of housing systems.

Nevertheless, Smits and Aarnink (2009) studied evaporation in CPB using a model approach. They estimated drying rate from a cultivated bedded pack by including in the model environmental parameters (e.g. air temperature, relative humidity and air velocity) and variables regarding the composting process. Results highlighted that environmental conditions are major factors influencing the drying rate and that heat produced by the composting process can considerably improve evaporation from the pack. In Dutch climatic conditions, drying rate from a pack that is actively composting may reach 3.6 kg/m^2 per day while a non-composting pack hardly exceeds 1 kg/m^2 per day (Smits and Aarnink, 2009).

Surprisingly, air velocity was negatively associated with drying rate. Especially during winter, high air speed may cause an excessive heat loss from the pack that, in turn, inhibits the composting process. Results obtained with the model approach are very useful for CPB management and design but they should be validated by field observations. Evaporation rates estimated by Smits and Aarnink (2009) suggested that, in Dutch climate, 9 m^2 of bedded area per cow might be adequate for CPB. However, more recent practical experiences with CPB in the

Netherlands showed that 12 to 15 m^2/cow have to be allotted to maintain the pack sufficiently dry during the winter period (Galama, 2014).

Black et al. (2013) investigated pack characteristics in Kentucky CPB. They estimated pack drying rate using a mass transfer equation. Calculated drying rates found in this study have not been published. However, evaporation was related to ambient temperature, relative humidity (RH), air velocity and pack surface temperature. Authors suggested that, while air temperature and RH are uncontrollable by producers, air velocity can be enhanced by proper barn ventilation and this may improve pack drying. As expected, drying rate significantly reduced pack moisture (Black et al., 2013). In Kentucky CPB, mean pack temperature at the surface was 10.5°C which was very similar to ambient temperature (9.9°C). Temperatures measured at a pack depth of 20.3 and 10.2 cm, were 36.1°C and 32.3°C, respectively. Pack temperature at 20.3 cm depth was affected by ambient temperature, tilling frequency and tilling depth (Black et al., 2013). Barberg et al. (2007a) studied CPB in Minnesota reporting a higher mean pack temperature of 42.5°C. Experiences with CPB in the Netherlands showed that in CPB using wood chips and aeration systems (composting bedded pack) pack temperature at 20 cm depth ranged from 34.6 to 57.7°C while in CPB using organic waste compost as bedding (compost bedded pack) pack temperature was between 16 and 34°C (Galama, 2014).

Since pack temperature improves drying, in CPB it is important to maintain optimal pack chemical and physical characteristics to support rapid and consistent bacterial growth. The composting process in a CPB may be affected by several parameters. The most important appear to be pack moisture, pH, oxygen availability and carbon to nitrogen (C:N) ratio. Stentiford (1996) indicated that higher compost temperatures tend to be achieved when pack moisture is between 40 and 60%. Studies on composting process indicated that faster organic matter degradation occurs when the C:N ratio is the range from 25:1 to 30:1 and pH from 6.5 to 8 (NRAES, 1992). Since aerobic processes produce more energy than those anaerobic, high oxygen availability is crucial for optimal composting (NRAES, 1992). Space allotment per cow can affect pack moisture because it modifies water input on the pack over time.

Besides that, dairy cows' excreta have a low C:N ratio, ranging from 15:1 to 19:1 (Rynk et al., 1992; Leonard, 2001). Most commonly used bedding materials are dry and have a very high C:N ratio. Rynk et al. (1992) reported C:N ratios of 600:1, 442:1 and 127:1 for wood chips, sawdust and wheat straw, respectively. In CPB adding fresh bedding may be necessary to absorb excessive pack moisture as well as keeping the pack C:N ratio within the optimal range. First reports regarding CPB management have recommended bedding addition when material sticks to the cows (Barberg et al., 2007a; Janni et al., 2007). However, Black et al. (2013) argued that cow hygiene and udder health is likely compromised at this point. Instead, adding shavings based on pack moisture appear to be a more viable recommendation. The combination of manure and substrate should not exceed a moisture content of 70%, although a range of 50 to 60% is preferred (Black et al., 2013).

To start a new cultivated pack most producers put down 25 to 50 cm of fresh bedding (Janni et al., 2007). Nevertheless, initial pack depth can vary widely from farm to farm ranging from 3.5 to 121.9 cm (Black et al., 2013). In most Minnesota CPB, producers added a semi-load of sawdust every two to five weeks, varying by season, weather conditions, and cow density. Normally, the amount of bedding added at a time provided 10 to 20 cm of fresh bedding across the pack (Barberg et al., 2007a). Another survey showed that, in Kentucky CPB, new bedding was added every 16.4 days during winter while every 18.2 days in summer. Kentucky producers added a mean depth of 8.8 cm of shavings per bedding addition, ranging from 0.1 to 35.3 cm (Black et al., 2013).

In Dutch CPB provided with aeration systems (composting bedded pack) wood chips was added approximately every 3 months (Galama, 2014). In a CPB using organic waste compost (compost bedded pack) the producer added fresh bedding every day during winter but, thanks to the large space per cow, he did not add any bedding during the rest of the year (Havermans, personal communication, 2014). In this kind of CPB heat development in the pack is not a priority and therefore fresh bedding is added primarily to absorb excessive pack moisture (Galama et al., 2011).

In all CPB systems, consistent pack cultivation is essential (Klaas and Bjerg, 2011). Stirring allows to incorporate fresh manure and air into the top layer of the pack providing a cleaner lying surface for the cows. In most CPB aerating is done with a modified cultivator on a skid loader or small tractor. Some farmers use a roto-tiller and some a combination of roto-tiller and tines cultivator (Barberg et al., 2007a). A well-managed pack is loose and fluffy and this improves aeration and microbial activity. In most of American and Israeli CPB the pack is cultivated twice daily while in the Netherlands cultivation occurs mostly once a day (Black et al., 2013; Galama, 2014). However, in some Dutch CPB (composting bedded pack) the pack is aerated many times per day by the aeration system installed in the floor below the pack (Galama, 2014).

The pack should be stirred at a depth of 25 to 30 cm (Janni et al., 2007). Increasing stirring frequency and depth led to higher pack temperature. Black et al. (2013) found about 10°C difference between pack stirred once and twice daily and cultivation depth was positively related to pack temperature. However, during winter, frequent aerations may result in an excessive heat loss from the pack, which disturb the composting process (Galama, 2014). For this reason, some Dutch producers modified pack management during colder months reducing both stirring frequency and depth (Havermans, 2014). Experiences with CPB in the Netherlands also suggested that, to maintain heat into the pack, at least 50 cm pack depth is necessary (Galama et al., 2011).

Cultivated pack barns design

Normally, CPB provide manure storage for six months to one year depending on barn design, pack management and kind of bedding (Barberg et al., 2007a; Galama, 2014). Farmers' experiences with CPB using organic waste compost and a pack density of about 15 m^2/cow indicate that the pack increases about 70 cm in depth during one year (Pijs, personal communication, 2014). In American CPB using mainly sawdust and a space allotment on the pack of 8.6 m^2/cow the bedded area was completely emptied once per year following fall harvest. However, some producers removed the top half of the pack in the spring (Barberg et al., 2007a). Typically, CPB in the US had either an indoor or outdoor concrete feed alley, a bedded pack (resting) area, and a 1.2 m high wall surrounding the pack (Barberg et al., 2007a). In this kind of CPB (Figure 1.1) the surface of the pack is at higher level compared with the concrete feeding alley. In the US the floor below the bedded pack can be made up of compacted clay or concrete depending on the State's regulation (Black et al., 2013).

In most European countries an impermeable floor below bedded areas is compulsory. In most Dutch CPB using organic waste compost as bedding (compost bedded pack) a plastic film covered with a layer of sand is placed under the pack to avoid nutrient seepage (Galama et al., 2011). In other Dutch CPB systems where the main bedding material is wood chips (composting bedded pack) the floor of the resting area is made up of concrete (in situ or precast elements). Most of CPB in the Netherlands are provided with a scraped or slatted feeding alley. In this kind of housing the floor under the bedded pack is placed at a lower level compared with the feeding area (Galama et al., 2011). To further reduce the risks of lameness and the production of liquid manure, one CPB in the Netherlands was built without a separated feeding alley and the surface of the barn was almost entirely bedded. In this barn cows were fed using feeding wagons placed directly on the bedded pack (Galama et al., 2011). To avoid excessive manure deposition in the areas where cows are fed, feeding wagons have to be moved every day (Havermans, personal communication, 2012).

In literature, little information is available about CPB design in Israel. However, some reports of technical visits in Israel led to think that most of Israeli CPB are provided with scraped feeding alleys (Klaas et al., 2010; Progressive Dairy Operators, 2011). Besides type and shape of floor, the roof of CPB can be built using different solutions. Roof type may influence widely the internal environment of the building and thus affect cows' performance. In CPB, environmental characteristics have been also related to the pack drying rate. Black et al. (2013) reported that, to improve pack drying and allow adequate removal of water vapor, high ventilation rates are desirable in CPB. Both natural and forced ventilation can affect pack drying and cows' performance. Therefore, particular attention has to be paid in designing a CPB.

Evaporation of water primarily depends on energy availability. In CPB sun radiation may be used as an additional source of energy, especially during winter, when air temperature and humidity limit the evaporative process from the bedded pack. Some CPB in the Netherlands have been built using greenhouse-type structure with transparent or semi-transparent claddings. Experiences with this type of buildings suggested that transparent roof can decrease the amount of bedding needed to keep the pack in adequate hygienic conditions (den Hollander, 2014). Greenhouse structures also allow a better control over barn ventilation since most of them are provided with automatic systems to control both sidewalls and ridge opening. Another advantage of greenhouse structure is the lower construction cost compared with "conventional solutions". Due to the warmer climate, greenhouse type roofs have not spread in Israel. However, some Israeli CPB are provided with retractable roof made up of opaque materials (Progressive Dairy Operators, 2011; Galama et al., 2011).

Animal welfare

The CPB concept was developed primarily to improve cow comfort. Many studies have been focused on cows' welfare and health in CPB. The main advantages appear to be related to hock lesions and lameness prevalence. Cows housed in CPB have healthier claws and legs likely due to the reduced concrete surfaces and less injury-causing obstacles in the barn compared with the free stall housing system. Although many authors expressed concerns about cow cleanliness and udder health in CPB, recent findings showed that, if properly managed, this housing system allow to keep cows in adequate hygienic conditions. Results regarding cow welfare obtained in different countries and with different types of CPB are summarized in Table 1.1.

Lameness and hock lesions. Lameness prevalence (proportion of cows with locomotion score ≥ 3 on a 1 to 5 scale, where 1 = normal and 5 = severely lame) in

CPB ranged from 4.4 to 25.0% while hock lesion prevalence (proportion of cows with a lesion score ≥ 2 on a 1 to 3 scale, where 1 = normal, 2 = hair loss, and 3 = swelling) varied from 0 to 46.9% (Table 1.1). Prevalence of lameness reported in most studies on CPB was much lower than the 24.6% (Espejo et al., 2006) and 27.8% (Cook, 2003) prevalence measured in FS. Although Ofner-Schröck et al. (2013) found a relatively high lameness prevalence of 25.0% in Austrian CPB, authors highlighted that this percentage is significantly lower than a series of results on FS (31-46%) obtained by the same research group.

Similarly, the prevalence of cows with hock lesions was mostly lower in CPB than in free stall systems. In a recent review article, Kester et al. (2014) found that the hock lesion prevalence in cows housed in FS is generally high and represent a problem in many herds. Weary and Taszkun (2000) reported a hock lesion rate of 73% in southern British Columbia, whilst other reported rates were 57% in France (Veissier et al., 2004); 50% in Austria and Germany (Brenninkmeyer et al., 2012); 47.3% in Denmark (Burow et al., 2012); 60.5% in Norway (Kielland et al., 2009); and 42, 56 and 81% in three regions of North America (von Keyserlingk et al., 2012).

Prevalence of cows with hock lesions reported in different studies on CPB varied widely. An important source of variation appeared to be the kind of material used as bedding. Shane et al. (2010) compared several bedding materials (sawdust, corn cobs, a mixture of wood chips and sawdust, a mixture of soybean straw and sawdust, a mixture of wood chips and soybean straw, and soybean straw) in CPB founding considerable differences in hock lesion prevalence among types of bedding. The mixture of wood chips and sawdust had the lowest hock lesion prevalence (0%) while soybean straw had the highest (46.9%). Moreover, among all the materials tested, only cows housed in CPB bedded with soybean straw and the mixture of soybean straw and sawdust had severe hock lesions (Shane et al., 2010). This suggests that using soybean straw in CPB may lead to increased hock lesion prevalence. However, also the characteristics of the floor in the feeding alley likely play a major role in determining the risk of hock lesions.

Fulwider et al. (2007) compared hock lesions in cows housed in CPB and in FS with different types of bedding. Cows in CPB had no lesions while in FS with rubber-filled mattress, sand and waterbeds hock lesion prevalence was 71.4, 25.0 and 35.2%, respectively. Lobeck et al. (2011) measured lameness and hock lesion prevalence in CPB, naturally ventilated FS and low profile cross-ventilated FS founding that cows housed in CPB have better feet and leg health compared with other housing systems. Lameness prevalence and hock lesion prevalence were lower in CPB (4.4 and 3.8%) than in cross-ventilated (15.9 and 31.2%) and naturally ventilated FS (13.1 and 23.9%). Improved feet and legs health of cows housed in CBP supports the concept that CPB housing system can reduce lameness by providing a softer standing (and walking) surface compared with FS (Black et al., 2013).

Cow hygiene and udder health. For many authors cow cleanliness in CPB can represent a matter of concern and, since bacterial count in cultivated pack is generally high, excellent teat preparation at milking has been largely recommended. The mean hygiene score (1 to 5 scale, where 1 = clean and 5 = very dirty) of cows housed in CPB ranged from 2.2 to 3.18 while the prevalence of dirty cows (proportion of cows with an hygiene score ≥ 3) varied from 21.1 to 51.2 (Table 1.1). Barberg et al. (2007b) in a study on CPB in Minnesota concluded that cow hygiene appear to be not negatively impacted by housing cows in CPB. Pack moisture is commonly recognized as the most important parameter in determining the hygiene level of the cows. As a matter of fact, providing a dry surface for cows to lie on is one overall goal of the CPB system (Black et al., 2013).

Both pack and ambient temperatures affect pack drying rate and, in turn, its moisture content. Black et al. (2013) found that in CPB increased pack and ambient temperatures improve mean herd hygiene. Lobeck et al. (2011) observed a similar relationship where hygiene score increased in the winter compared with the summer. The highest percentage of cows scored as dirty (51.2%) was found in Israeli CPB (Klaas et al., 2010). Due to the warm climate, producers with CPB in Israel do not add any bedding materials. Authors noted that the farm with cleaner cows had a high pack temperature while a relatively high number of dirty cows was found in CPB where the pack did not generate adequate heat. This emphasizes the importance of keeping the pack worm and that pack management is crucial for this type of housing system.

Shane et al. (2010) tested several bedding materials in CPB reporting hygiene scores that range from 2.4 to 2.9. They found no significant difference in hygiene score among the different materials. Fulwider et al. (2007) reported that cows on rubber-filled mattresses or waterbeds were cleaner than cows on sand-bedded free stalls, and noted that CB barns had similar hygiene scores to waterbed-housed cows. In a recent Dutch research, the hygiene level of cows housed in CPB, SY and FS was compared. The CPB had, on average, the cleanest cows followed by FS and SY (Ouweltjes and Smolders, 2014). Authors concluded that, with proper management, it is possible to keep the animals sufficiently clean in CPB. In spite of that, Lobeck et al. (2011) found higher hygiene score in CPB (3.18) compared with cross-ventilated (2.83) and naturally ventilated FS (2.77).

The mean somatic cell count (SCC) of cows housed in CPB ranged from 111,000 to 434,000 cells/mL (Table 1.1). Black et al. (2013) found that summer-season SCC were higher compared with spring, fall, and winter. Results obtained by Fulwider et al. (2007) demonstrated that severe leg lesions are correlated with SCC. Even though differences were not statistically significant, CPB had lower SCC (176,700 cells/mL) than FS with rubber-filled mattress (241500 cells/mL), sand (235,200 cells/mL) and waterbeds (232,500 cells/mL). Lobeck et al. (2011) instead, found that cows housed in CPB have higher SCC (434,000 cells/mL) than those in cross-ventilated (309,000 cells/mL) and naturally ventilated FS (300,000 cells/mL). Shane et al. (2010) reported no differences in SCC among the different types of bedding material tested in CPB.

Mastitis infection prevalence (proportion of cows with SCC > 200,000 cells/mL) in CPB was measured in just two studies ranging from 27.7 to 33.4% (Table 1.1). Barberg et al., (2007b) performed a comparison of mastitis infection rates before and after housing the herds in a CPB. Six out of 9 dairies had a reduction in herd mastitis infection rates with an average reduction of 12.0%. Lobeck et al. (2011) found mastitis infection prevalence of 33.4, 26.8, and 26.8% for CPB, cross-ventilated, and naturally ventilated FS, respectively, with no significant differences among housing systems. A Dutch report showed that after housing cows in CPB their udder health was not altered, nay, in the CPB studied the use of antibiotics was significantly reduced (Ouweltjes and Smolders, 2014). Surprisingly, no studies found correlations between hygiene score and SCC or mastitis infection prevalence in CPB.

Body condition. Body condition score (BCS, on a 5-point scale, where 1 = emaciated and 5 = obese) of cows housed in CPB was measured in various studies ranging from 2.9 to 3.3 (Table 1.1). Ouweltjes and Smolders (2014) stated that BCS of cows in CPB is in the optimal range for dairy cattle. Shane et al. (2010) reported that different bedding materials in CPB do not affect BCS. Lobeck et al. (2011) found no differences in BCS among CPB, cross-ventilated, and naturally ventilated FS. Seasonally, BCS were higher in the winter than in summer and fall with no differences between spring and winter. Spring BCS were greater than summer BCS. Multiparous cows had greater BCS than primiparous cows (Lobeck et al., 2011).

Culling. The culling rate (or herd turnover rate) describes the percentage of cows removed from a herd in a unit of time (often one year). Cows can be voluntary culled by the producer when the challenger replacement cow is expected to generate more profit. However, culling is often involuntary. Involuntary culling includes cow culls due to illness, injury, infertility, or death (Hadley et al., 2006). A high proportion of involuntary culling in the herd indicates poor animal welfare (Ahlman et al., 2011). Although no single turnover rate is optimal for all herds or for all years, research has consistently estimated optimal herd-level culling rates ranging from 19 to 29% (Hadley et al., 2006). In a review article, Fetrow et al. (2006) reported that, since replacing cows is a major cost of operation, lower annual turnover rates are more profitable, with optimal turnover rates of ≤30%. Actual average annual culling rates are often above the optimal range. In 2001, the average annual culling rate for Upper Midwest of the US was 38% (Quaiffe, 2002). More recently, Pinedo et al. (2014) found an average annual turnover rate of 35% for Holstein cows. Today's high involuntary culling rates are a concern on dairy farms from both an animal well-being and an economic point of view (Weigel et al., 2003).

Annual herd turnover rates in CPB have been reported in many studies ranging widely from 20.4 to 37.8% (Table 1.1). Barberg et al. (2007b) found that mean culling rate decreased from 25.4% to 20.9% after moving cows to CPB. Fullwider et al. (2007) reported lower herd turnover rate for CPB (20.4%) than FS with rubber-filled mattress (29.4%), sand (25.6%) and waterbeds (22.8%). These results suggest that CPB may reduce culling rate. Conversely, Lobeck et al. (2011) found higher herd turnover rate in CPB (30.1%) compared with cross-ventilated (24.6%), and naturally ventilated FS (29.0%), although differences were not significant. The top reasons for cow culls in CPB barns were breeding (24.0%), mastitis (20.2%), and sick or injured (19.3%). When comparing the percentages of reasons for leaving the farm, housing systems did not differ for mastitis, production, breeding, dairy, sick or injured, or miscellaneous (Lobeck et al., 2011).

Ouweltjes and Smolders (2014) found relatively high culling rate in three Dutch CPB. However, authors reported that in the farm with the highest turnover rate (37.8%) most of the cows were still alive 30 days after culling indicating that those animals were voluntary sold. On average, in Dutch CPB just 13.8% of the cows that left the herds were slaughtered within 30 days after culling (Ouweltjes and Smolders, 2014). Since cows housed in CPB generally have better health compared with FS (especially for legs and feet), an improvement in culling rate could be expected. Most of the herd turnover rates found in CPB are lower than those reported for FS. Nevertheless, culling data for CPB obtained in different studies appeared to be not consistent indicating that further and more definitive investigation is deserved.

Cow behavior and reproductive performance. Cows express a complex set of behaviors and social interactions. Type of housing can allow or hinder natural behavior affecting animal welfare. An overall goal of loose-housing systems such as CPB is to allow cattle freedom of movement. Cows should be able to perform the natural movements associated with getting up and lying down without injury (Fulwider et al., 2007). Haley et al. (2001) reported that dairy cattle spend 8 to 16 h/d lying down, which emphasizes the importance of the lying surface to the animal. Cows provided with a softer bed are known to rest longer and to stand up and lie down more often than cows on concrete (Haley et al., 2001). The number of times a cow stands up and lies down each day and the duration of each lying bout, as well as the total lying time, may be used to measure the comfort of the lying surface and housing system (Endres and Barberg, 2007).

Endres and Barberg (2007) observed the behavior of cows housed in CPB. They reported an overall mean lying time of 9.99 h/day (excluding cows that had access to pasture). Mean number of lying bouts per day was 11.0 while the lying bout duration was 50.8 min. The cows housed in CPB spent a greater amount of time lying at night (6.8 h from 20:00 to 08:00 h) than during the day (2.8 h from 08:00 to 20:00 h). Lying time and walking behavior in CPB was affected by the temperature-humidity index (THI). Cows rested longer and walked less when the THI was <72 (12,7 h/day and 71.6 steps/h) than when the THI was ≥72 (7.90 h/day and 120.8 steps/h). Authors noticed that CPB generally provide a soft and cushioned lying surface that allows cows to stand up and lie down without apparent discomfort and that cows were able to move freely on the bedded pack (Endres and Barberg, 2007).

Ouweltjes and Smolders (2014) measured the time that cows needed to lie down in CPB and FS. Cows housed in FS needed more time to lie down (6.3 s) than those in CPB (4.8 s). This may indicate that cows feel the bedded pack more comfortable than free stalls (Welfare Quality®, 2009). Time needed to lie down in CPB was also compared with that in SY finding that cows in SY lie down quicker than in CPB even though both these housing systems provide an open resting area with few or no movement restrictions. This might be caused by the daily cultivation of the bedded pack that made it very soft. As a matter of fact when the pack is too soft cows had to pull out their legs from the bedding before lying down leading to an increase of the time needed to lie down of about one second (Ouweltjes and Smolders, 2014). This indicates that the bedded pack should be soft to provide a comfortable and healthy surface but also have an adequate bearing capacity.

Cows social interaction was observed either in American and Dutch CPB. Results indicated that cows housed in CPB have few negative interaction than those in FS and that social behavior in CPB is similar to that observer in cows at pasture (Endres and Barberg, 2007). Ouweltjes and Smolders (2014) also found more frequent positive interactions (allogrooming, or social licking) in herds housed in

CPB than in other housing systems. Endres and Barberg (2007) concluded that, from a behavioral standpoint, CPB can be an adequate housing system for dairy cows, because their observations were not substantially different from those reported in literature with other types of housing.

The softer CBP surface provides cows with a better footing for estrus behavior expression and thus may positively affect fertility. Black et al. (2013) observed an improvement in reproductive parameters from the year before to the second year after moving cows to CPB. Calving interval, days to first service and days open passed from 14.3 to 13.7 months, from 104.1 to 85.3 d, and from 173.0 to 153.4 d, respectively, after CPB occupation. An increase in the percentage of heats observed occurred from the year before to the year after CPB occupation (42.0 to 48.7%). However, the pregnancy rate and the conception rate remained unaltered after the transition to CPB (Black et al., 2013). Barberg et al. (2007b) also measured an improvement in reproductive performance in 7 dairies after moving cows to CPB. Four of the 7 dairies had an increase in heat detection rate of 20.3 to 32.8%, with an average increase of 25.9%. The pregnancy rate for the 7 dairies prior to being housed in CPB was 13.2%, and 16.5% after CPB occupation. Five farms had an increase in pregnancy rate of 21.9 to 48.6%, with an average increase of 34.5% (Barberg et al., 2007b).

Welfare around calving. Little is still know about the effects of CPB housing system on the welfare of cows during the transition period. Nevertheless, a recent study from Astiz et al. (2014) compared welfare and performance around calving of cows housed in different housing systems. Results showed clear benefits of housing dairy cows during the dry period in CPB systems when compared with a SY system based on barley straw. Positive effects of CPB regarded mainly udder health in the early lactation. Compared with SY, cows that spent the dry period in CPB had lower incidence of the first mastitis-cases (22.1 vs. 35%), of second-mastitis cases (6.8 vs. 15%), and a positive tendency in SCC (96100 vs. 139500 cells/mL). No differences in pregnancy after first insemination, mortality rate, and in the incidence of clinical metritis and endometritis among housing systems were detected (Astiz et al., 2014).

Although further studies are deserved in this field, authors concluded that the implementation of CPB systems in dairy farms should be encouraged.

Bedded pack bacterial analysis

Since the main objective in CPB is to maintain a dry surface while reducing barn size and the need for fresh beddings, producers should target high pack temperatures that improve water evaporation from the pack (Black et al., 2013). During composting, temperatures between 45 and 55°C maximize material degradation whilst compost temperatures above 55°C promote sanitization (Stentiford, 1996). Pack temperatures measured in CPB indicate that the pack is biologically active but they are not sufficient to support neither a full composting process nor pathogens devitalization. Most mastitis-causing bacteria thrive in the conditions that have been reported in CPB (Black et al., 2014).

Mean total bacterial counts measured in various CPB using different bedding materials ranged from 6.5 to 8.4 log_{10} cfu/g. Counts for coliforms, environmental streptococci, *Staphylococcus* spp., and *Bacillus* spp. ranged from 4.1 to 7.0 log_{10} cfu/g, from 3.0 to 7.5 log_{10} cfu/g, from 4.0 to 7.9 log_{10} cfu/g and from 4.4 to 7.6 log_{10} cfu/g, respectively (Table 1.2). On average, *Bacillus* spp. were the most prevalent bacteria followed by environmental streptococci, coliforms and *Staphylococcus* species. Concentration of *Escherichia coli* has been measured in just two studies that reported quite different counts of 6.0 (Balck et al., 2014) and 2.4 log_{10} cfu/g (Driehuis et al., 2012). *Klebsiella* counts in cultivated packs also varied widely from 2.4 to 5.9 log_{10} cfu/g (Table 1.2). Wood materials such as wood shavings and sawdust are known to increase the likelihood of exposure to *Klebsiella* spp. pathogens (Newman, 1973; Janni et al. 2007). Shane et al. (2010) also reported that coliforms were numerically higher in wood materials that might be an indication that those species of bacteria have a preference for that type of substrate. In CPB, *Bacillus* spp. and *Klebsiella* spp. counts tend to be higher in the summer than in the winter (Lobeck et al., 2012).

Black et al. (2014) studied factors affecting bacterial counts in Kentucky CPB showing that pack temperature, pack moisture, C:N ratio, and space per cow had no effect on coliform counts. *E. coli* reached a peak concentration when the C:N ratio was between 30:1 and 35:1. Staphylococci counts increased as ambient temperature increased. Streptococci counts decreased with increased space per cow and pack temperature and increased with increasing ambient temperature and moisture. Streptococci counts peaked at a C:N ratio ranging from 16:1 to 18:1. *Bacillus* spp. counts were reduced with increasing moisture, C:N ratio, and ambient temperature. Lobeck et al. (2012) compared bedding bacterial counts in CPB, naturally ventilated FS and low profile cross-ventilated FS. They found no difference among housing systems for *Klebsiella*, coliforms, environmental streptococci and *Staphylococcus* spp. counts. During winter *Bacillus* spp. count was lower in CPB than in cross-ventilated and naturally ventilated FS while in the summer CPB had grater *Bacillus* spp. level.

Milk production and quality

Milk production was measured in various studies on CPB. It appears that the potential improved cow comfort in CPB could result in increased milk production (Barberg et al., 2007b). Barberg et al. (2007b) found that 8 out of 9 dairies had an increase in 305-d mature equivalent milk production after shifting to CPB. On average the increase was 955 kg. Similarly Black et al. (2013) reported a significant increase in milk yield after moving cows into the CBP. Daily milk production increased from before moving into the CBP (29.3 kg/d) to the second year after barn occupation (30.7 kg/d). Rolling herd milk yield average increased from 8937 to 9403 kg. However, the effect of CPB housing system on milk production is still not completely clear. Authors acknowledged that, besides housing system, changes in management probably occurred in the process of changing to CPB that could have contributed to the observed increase in milk production (Barberg et al., 2007b; Black et al., 2013). As a matter of fact, Lobeck et al. (2011) found similar 305-d mature equivalent milk production in CPB (11,154 kg), cross-ventilated (11,536 kg), and naturally ventilated FS (11,236 kg).

Bedding containing greater than 10^6 cfu of total bacteria/g are believed to increase intramammary infection risk (Jasper, 1980). Therefore, since reported bacterial counts in cultivated packs are higher (Table 1.2), the CPB environment appears to be quite hazardous from an udder health standpoint. Most authors recommended excellent teat preparation procedure at milking to maintain low SCC in herds housed in CPB (Janni et al., 2007, Lobeck et al., 2012, Black et al, 2014). Moreover, bedding should be kept as dry and clean as possible by appropriate new bedding addition to the pack (Shane et al., 2010). Milk quality parameters and bacterial analysis reported in various studies on CPB are summarized in Table 1.3. Milk fat and milk protein content ranged from 3.06 to 3.88 and from 3.09 to 3.30, respectively. Barberg et al. (2007b) found that after shifting from tie-stall to CPB three out of nine dairies increased milk fat content by 9.8% and milk protein content by 3.5%. Authors highlighted that these observations deserve further and more definitive investigation but no studies have been focused on milk fat and protein content in CPB so far.

Average SCC in CPB varied from 111,000 to 434,000 cells/mL (Table 1.3). Barberg et al. (2007b) reported an average SCC of 325,000 cells/mL in 9 CPB that was lower than the average SCC for Minnesota herds. In the same study, it was found that three out of 7 dairies had a significant reduction in bulk tank SCC (BTSCC) after moving cows to CPB. The reduction in BTSCC in the 3 dairies was 90310 cells/mL (Berberg et al., 2007b). Another study carried out in Kentucky reported lower SCC in CPB (246500 cells/mL) compared with the average SCC in the same state (Black et al., 2013). Black et al. (2013) also found a reduction in BTSCC from the year before moving cows into CPB (323,700 cells/mL) to the year after (252,900 cells/mL). Shane et al. (2010) reported that milk had much lower bacterial counts than bedding. Moreover, no relationship appeared to be between SCC and high count of bacteria found on the surface of the pack.

Barberg at al. (2007b) found a mean total bacterial count in milk from CPB of 3420 cfu/mL. Results obtained from milk bacterial analysis showed that, in CPB, mean concentrations of coliforms, non-ag *Streptococcus*, *Staphylococcus* spp., and *Staphylococcus aureus* ranged from 2.8 to 1058.1 cfu/mL, from 6.0 to 878.4 cfu/mL, from 2.9 to 52.6 cfu/mL and from 0.0 to 5.7 cfu/mL, respectively (Table 1.3). Lobeck et al. (2012) compared milk bacterial counts in CPB, naturally ventilated FS and low profile cross-ventilated FS founding no differences among housing systems. However, in all housing systems coliforms in milk were significantly higher in summer than in winter.

The TAS/XTAS issue. In recent years, an important Dutch dairy cooperative noticed that milk from CPB can cause some spoilage problems in long-life dairy products that were considered to be microbiologically sterile (Galama et al., 2014). Further researches demonstrated that the use of green waste compost and composting wood chips as bedding for dairy cows can cause milk contamination by thermophilic aerobic sporeformers bacteria (TAS) and by a subpopulation of bacteria that produces extremely heat-resistant spores (XTAS). Spores produced by TAS and XTAS bacteria can survive standard milk sterilization processes causing problem in the shelf life of some dairy products (Driehuis et al., 2014). For this reason, the Dutch dairy company decided to forbid the use of compost as bedding for dairy cows starting from the 1st January 2015 (Galama et al., 2014). Actually, the prohibition does not regard composting wood chips although this material also represents a matter of concern.

Researches from Driehuis et al. (2014) investigated the presence of TAS and XTAS in various types of beddings and in milk from CPB. Spores of both TAS and XTAS were detected in beddings while only TAS were found in milk. Concentration of XTAS cannot be determined in tank milk because concentrations were below the limit of detection. High concentrations of TAS and XTAS spores were detected in compost and composting wooden chips. From the bedded pack, TAS and XTAS bacteria can contaminate the cow’s teats. Although they are not believed to produce intramammary infections in cows, TAS and XTAS from contaminated udders are transferred in milk (Driehuis et al., 2012). Due to the high concentration of spores in compost and composting wood chips beddings, teat cleaning operations have shown to be insufficient to avoid milk contamination (Driehuis et al., 2014).

Mean concentrations of TAS and XTAS in compost were 6.9 $\log_{10}$ cfu/g and 4.1 $\log_{10}$ cfu/g, respectively. *Aeribacillus* and *Geobacillus* spp. were the predominant XTAS species, whereas *Bacillus thermoamylovorans* was the predominant TAS (Driehuis et al., 2014). In compost, XTAS spores were, on average, 1000 times higher than in sawdust and straw bedding. Spores of TAS and XTAS are likely produced during the composting process of municipal bio-waste. Generally, TAS and XTAS spores were lower in composting wood chips than in compost. Fresh wood chips did not appear to be a relevant source of these bacteria but, since in CPB the bedded pack reaches relatively high temperature, TAS and XTAS spores may be produced at the farm level. Driehuis et al. (2014) reported that concentrations of TAS and XTAS in CPB using wood chips as bedding likely depend on the intensity of the composting process in the pack.

Other bedding materials such as sawdust, straw and separate manure solids showed very limited concentration of TAS and XTAS compared with compost and composting wood chips (Galama et al., 2014). For this reason, in the last few years, many producers tried to use wheat straw in CPB that was originally developed for compost or wood chips. Results appear to be encouraging. In a study carried out in the Netherlands, milk quality as well as performance and welfare of cows housed in CPB using compost, composting wood chips and straw were compared. In CPB using straw, lower concentrations of TAS and XTAS were found in milk. Furthermore, cows housed on straw bedding had the lowest SCC (Galama et al., 2014) indicating that straw can represent a viable alternative to compost and wood materials in CPB.

Bedded pack characteristics and manure quality

Bedded pack from CPB has been analyzed in many studies. Both chemical and bacterial analyses have been performed. Obviously, the characteristics of a bedded pack depend on type of bedding material and pack management as well as cows' diet composition. Temperature, moisture and chemical analysis of bedded pack from CPB obtained in different studies are reported in Table 1.4. Mean pack temperature ranged from 10.5 to 42.5°C (Table 1.4). Black et al. (2013) found that temperature at the pack surface (10.5°C) was very similar to ambient temperature because evaporation and ventilation cool the surface of the pack. Temperature tended to increase with depth. In an experiment carried out by Shane et al. (2010) soybean straw had the lowest temperature while corn cobs had the highest. Nevertheless, the highest pack temperature among all studies was obtained with sawdust (Barberg et al., 2007a).

The mean pH level measured in various CPB with different bedding materials ranged from 7.4 to 8.8 (Table 1.4), which is included, or slightly above the recommended pH level for composting of 6.5 to 8.0 (NRAES, 1992). The mean C:N ratio showed a wide field of variation from 10.5 to 49.3 (Table 1.4). Wood materials such as sawdust and wood chips were expected to have a higher C:N ratio (Shane et al., 2010). However, only few studies reported a C:N ratio in CPB that lie in the optimal range for composting (25:1 to 30:1; NRAES, 1992). Mean pack moisture in almost every study was comprised in the optimal range for this housing system (from 41.2 to 62.3%; Table 1.4) indicating that, while most producers were able to keep the pack sufficiently dry, maintaining optimal C:N ratio in CPB can pose some challenges.

Nutrient analysis of bedded pack from CPB showed that N, P e K contents range from 1 to 3.57%, from 1050 to 6589 mg/kg and from 3893 to 44,084 mg/kg, respectively (Table 1.4). A Dutch research revealed that composition, C decomposability and N mineralization rate of manure from CPB are largely similar to regular green waste compost. In the long term, the use of manure from CPB as fertilizer can result in considerable higher amounts of soil organic matter and larger accumulation of organic N compared with liquid cattle manure. However, manure from CPB is not suitable as a short-term N fertilizer due to low content of mineral N and slow N mineralization rate (de Boer, 2014). Plausibly, the N availability to the soil may be improved by continued manure composting once removed from the CPB (Black et al., 2013; de Boer, 2014).

Gaseous emissions

During the composting process C:N ratio and pH affect ammonia volatilization. A C:N ratio below 25:1 may result in increased ammonia emission (Rosen et al., 2000). The pH level controls the equilibrium between ammonium ions and ammonia. At high pH this equilibrium is displaced towards ammonia (NH_3) and so its volatilization may be fostered (Jeppsson, 1999). The high pH and the relatively low C:N ratio found in CPB (Table 1.4) suggest that pack conditions are conducive for NH_3 loss (Shane et al., 2010). Just few studies have been focused on gaseous emission in CPB and almost all of them have been carried out in northern Europe, where the laws about emissions in agriculture are more restrictive compared with most countries.

Van Dooren et al., (2011) studied emissions of NH_3, methane (CH_4) and carbon dioxide (CO_2) in CPB bedded with three different materials: sand, composting wood chips and a mixture of peat and reeds which is known in the Netherlands as “toemaak”. On average, emissions from the surface of the pack bedded with sand for NH_3, CH_4 and CO_2 were 415 mg/m^2*h, 0.04 g/m^2*h and 22 g/m^2*h, respectively. In a CPB bedded with compost emissions of NH_3, CH_4 and CO_2 were 227 mg/m^2*h, 1.4 g/m^2*h and 101 g/m^2*h, respectively. The pack bedded with peat and reeds emitted 182 mg/m^2*h, 0.6 g/m^2*h and 18 g/m^2*h of NH_3, CH_4 and CO_2, respectively (van Dooren et al., 2011). Sand bedding had the highest ammonia emission while compost emitted more methane and carbon dioxide than other materials.

Van Dooren et al. (2011) also compared ammonia emission in CPB bedded with the materials previously described and in a free stall barn with fully slatted floor. All the CPB considered had a slatted feeding alley. Regardless of the housing system, ammonia emission from the areas with slatted floor (with slurry pit below) was 1200 mg/m^2*h, and therefore the NH_3 emission per square meter of slatted floor was much higher compared with bedded pack. Nevertheless, since in CPB the space allotment per cow was higher than in free stall barn, the total ammonia emission per cow in CPB was similar or even higher than in free stall barn, depending on the bedding material. In CPB bedded with sand total NH_3 emission per cow (bedded area + slatted floor) was 80% higher than in free stall barn while in CPB bedded with organic materials (compost or peat and reeds) the total ammonia emission was just 5 to 10% higher (Galama et al., 2011). These results indicated that the biological processes in organic bedded packs might reduce gaseous nitrogen losses likely because bacteria use part of the nitrogen contained in cattle excreta during the degradation of organic matter. On the other hand, organic bedding materials lead to increased emissions of CO_2 and CH_4 compared with non-organic materials such as sand.

Another Dutch study from de Boer (2014) focused on nitrogen balance in CPB and in a free stall barn. The two type of CPB considered were bedded with green waste compost or composting wood chips and both of them had a slatted feeding alley while the free stall barn had a fully slatted floor. In this study gaseous nitrogen losses in the barn as well as those produced during land application of manure were examined. At the barn level, the percentages of nitrogen lost over the total nitrogen excreted by the cows were 19.0%, 43.9% and 8.9% for the CPB with composting wood chips, CPB with green waste compost and free stall barn, respectively (de Boer, 2014). In the CPB most of the nitrogen was emitted from the bedded pack rather than from the slatted feeding alley. During land application of manure produced in CPB with composting wood chips, CPB with green waste compost and free stall barn, 4.8%, 3.9% and 8.7% of the total nitrogen excreted were emitted, respectively (de Boer, 2014). Nitrogen losses in this phase for manure produced in CPB were entirely caused by the liquid manure collected in the slatted alleys while emissions derived by land application of bedded pack materials were negligible. Although nitrogen losses at land application of manure were lower for CPB, the total nitrogen loss was higher for CPB with green waste compost (43.9%) and for CPB with composting wood chips (23.8%) than for the free stall barn (17.6%).

De Boer (2014) argued that gaseous nitrogen losses in CPB mainly consist of NH_3, nitrous oxide (N_2O) and nitrogen gas (N_2) but no direct measures were performed for N_2O and N_2. Lobeck et al. (2012) measured aerial concentrations of NH_3 and hydrogen sulfide (H_2S) in CPB, low profile cross-ventilated and naturally ventilated FS located in the upper mid-west of US. Ammonia concentrations were 3.9 ppm in CPB, 5.2 ppm in cross-ventilated FS and 3.3 ppm in naturally ventilated FS. The cross-ventilated barns had greater ammonia concentrations than CPB and naturally ventilated FS, whereas CPB and naturally ventilated FS did not differ (Lobeck et al., 2012). Hydrogen sulfide aerial concentrations were 13, 32 and 17 ppb in CPB, cross-ventilated and naturally ventilated FS, respectively. Cross-ventilated

FS had higher H_2S concentration than other housing systems with no differences between CPB and naturally ventilated FS (Lobeck et al., 2012). In all housing systems studied by Lobeck et al. (2012) the highest concentration of NH_3 was measured in summer while H_2S was higher during winter.

Economics

Construction costs as well as costs and availability of bedding for CPB may represent a matter of concern. Some authors from the US reported that CPB have lower investment costs compared with FS because of the reduced concrete requirement and the lack of stall hardware (Barberg et al., 2007a; Janni et al., 2007). However, some states in US require a concrete base under the pack to reduce nutrient seepage and, in comparison with FS, more space per cow is necessary to maintain adequate hygienic conditions in CPB. Obviously, CPB construction costs primarily depend on space allotment per cow. Barberg et al. (2007a) reported building costs per cow place for CPB in Minnesota ranging from \$625 to \$1750. The average cost per cow based upon a uniform space allowance of 7.4 m^2 per cow was \$1200. Black et al. (2013) studied CPB in Kentucky founding a barn cost per cow of \$1051 (assuming 9.3 m^2 per cow). Producers spent \$78.77 per m^2 of barn area including the feed alley. Comparing construction costs of CPB with FS, Black et al. (2013) showed that CBP cost \$900 or 46% less per cow than a free stall barn with mattress-based free stalls and \$750 or 42% less per cow than free stall barn with sand bedded free stalls. However, it has to be considered that CPB built within the state of Kentucky do not require a concrete base (Black et al., 2013).

Higher building costs for CPB have been reported in Dutch studies. Galama et al. (2011) calculated building costs of 3138 € per cow place for CPB with compost bedding and 2580 € per cow place for CPB bedded with composting wood chips (including feeding alley and manure storage facilities). When compared with a free stall barn (with fully slatted floor) the cost per cow place for a CPB with compost bedding was 128 € higher while a CPB with composting wood chips was 430 € per cow cheaper. However, CPB construction costs were calculated assuming space allotments in the resting area of 15 m^2 per cow in CPB with compost bedding and 8

m^2 per cow in CPB bedded with composting wood chips (Galama et al., 2011) even though more recent studies indicated that 12 to 15 m^2 per cow are necessary in CPB under Dutch climate conditions (Galama, 2014). Galama et al. (2014) analyzed construction costs of the two main type of CPB in the Netherlands assuming 15 m^2/cow in the resting area either for CPB with green waste compost bedding and for those bedded with composting wood chips. Results showed higher building costs for CPB with composting wood chips (4309 € per cow place) than for CPB with compost (3709 € per cow place). Moreover, the cost for compost-bedded CPB was similar to that estimated for a free stall barn with full slatted floor (3667 € per cow place). The higher construction cost for the CPB bedded with composting wood chips was due to the forced aeration system installed in the floor below the pack (Galama et al., 2014).

Costs and availability of bedding was reported to be the main concern by producers with CPB (Barberg et al., 2007b). In Minnesota CPB the cost for bedding (dry fine wood shavings or sawdust) ranged from $0.35 to $0.85/cow per day (Barberg et al., 2007b). Janni et al. (2007) found that, in CPB with a space allotment of 7.4 m^2/cow, 19.6 m^3/cow of dry fine sawdust is consumed resulting in a cost of $181/cow per year or $0.50/cow per day. Black et al. (2013) examined bedding costs in Kentucky CPB. Producers used different materials including kiln-dried sawdust or shavings, green sawdust or shavings, and a mixture of kiln-dried sawdust or shavings and green sawdust or shavings, or soy hulls. The mixture of dry and green wood materials or soy hulls was the most expensive ($9.45 per m^3) followed by kiln-dried sawdust or shavings ($8.19 per m^3) and green sawdust or shavings ($3.30 per m^3). On average, bedding consumption ranged from 0.07 m^3/cow per day for the mixture of dry and green wood materials or soy hulls and for green sawdust or shavings to 0.05 m^3/cow per day for kiln-dried sawdust or shavings. Mean costs of bedding were found to be $0.35, $0.26 and $0.70/cow per day for kiln-dried sawdust or shavings, green sawdust or shavings, and a mixture of kiln-dried sawdust or shavings and green sawdust or shavings, or soy hulls (Black et al., 2013).

Shane et al. (2010) tested different bedding materials in CPB. They found bedding consumptions of 8.8, 15.2, 14.8, 11.1, 26.7 and 16.9 kg/cow per day for sawdust, corn cobs, mixture of wood chips and sawdust (on a 2:1 volume-to-volume ratio), mixture of soybean straw and sawdust (on a 2:1 volume-to-volume ratio), mixture of wood chips and soybean straw (on a 2:1 volume-to-volume ratio) and soybean straw, respectively. Cost of bedding materials were $0.12, $0.04, $0.02 and $0.09 per kilogram for corn cobs, sawdust, wood chips and soybean straw, respectively. The costs of bedding per cow and per day was $0.35, $1.90, $0.45, $0.85, $0.60, and $1.45 for sawdust, corn cobs, mixture of wood chips and sawdust, mixture of soybean straw and sawdust, mixture of wood chips and soybean straw, and soybean straw, respectively (Shane et al., 2010).

Except for corn cobs and soybean straw, costs of bedding per cow reported by Shane et al. (2010) were similar to those found by Barberg et al. (2007b), Janni et al. (2007) and Black et al. (2013). These results indicate that, in the upper mid-west of US, the cost of bedding in CPB using wood materials (and a space allotment in the resting area of 6.9 to 12.0 m^2/cow) would be comprised between $0.26 and $0.85/cow per day. Black et al. (2013) compared bedding costs in CPB and in FS founding lower costs of $0.18/cow per day for sand bedded free stalls and $0.13/cow per day for mattress-based free stalls. Although the CPB housing system likely has larger bedding costs compared with FS, the substantial improvements in cow welfare and health, such as low lameness prevalence, could offset these costs (Barberg et al., 2007b). However, cost of bedding materials can vary largely depending on country, region, hauling distance from the source and economic context. Moreover, CPB located in different countries and regions may require different amount of beddings due to climate variations.

Galama et al. (2011) estimated costs of bedding in two types of CPB in the Netherlands. Bedding costs were 0.21 €/cow per day for a CPB bedded with compost and 0.11 €/cow per day for a CPB with composting wood chips and forced aeration. In this study it was assumed a cost of 10 €/m^3 for green waste compost and of 5 €/m^3 for wood chips. More recently, Galama (2014) measured bedding consumption and costs in three existing Dutch CPB. Results highlighted bedding consumption of 13.7 kg/cow per day in CPB bedded with composting wood chips and from 22.8 to 42.8 kg/cow per day in compost-bedded CPB. The cost of wood chips ranged from 0.035

to 0.045 €/kg while the cost of compost from 0.008 to 0.014 €/kg. The costs of bedding per cow and per day varied from 0.48 to 0.62 € for CPB bedded with composting wood chips and from 0.18 to 0.60 € for compost-bedded CPB (Galama, 2014). Last data available on bedding costs in Dutch CPB indicate a cost of 0.46 €/cow per day for CPB with composting wood chips and forced aeration and 0.33 €/day for CPB bedded with compost (Galama et al., 2014). In all Dutch studies regarding bedding consumption and economics in different housing system, CPB had higher bedding consumption and costs compared with FS (Galama et al., 2011; Galama et al., 2014).

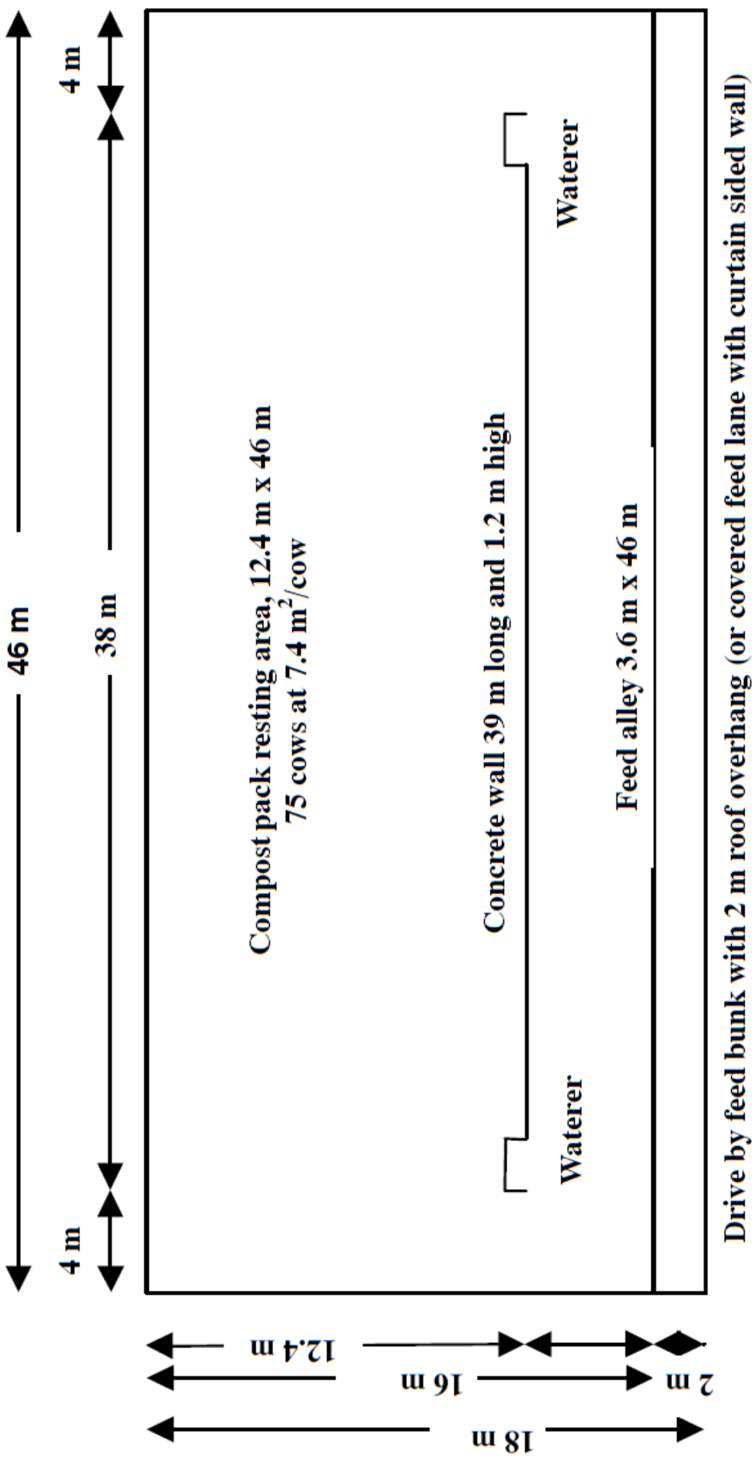

Figure 1.1. Layout of a CPB (not to scale) for 75 cows with two walkways, drive-by feeding and 2-m overhang. Waterers are against the concrete wall separating the bedded pack area from the feed alley and are accessed from the feed alley only (from Barberg et al., 2007a).

Table 1.1. Welfare-related parametersof cows housed in CPB.

		Lameness		Hock lesions		Udder health			Hygiene		
Reference	Bedding material[1]	Lameness prevalence[2] %	Severe lameness prevalence[3] %	Hock lesion prevalence[4] %	Severe hock lesion prevalence[5] %	Mastitis infection prevalence[6] %	SCC cells/mL	BCS[7]	Hygiene score[8]	Dirty cows prevalence[9] %	Annual herd turnover rate[10] %
Balck et al., 2013	SD	11.9	5	NA[11]	NA	NA	275,510	NA	2.2	29.8	NA
Lobeck et al., 2011	SD	4.4	0.8	3.8	0.8	33.4	434,000	2.91	3.18	NA	30.1
Ofner-Schröck et al., 2013[12]	SD	25	NA	NA	NA	NA	NA	NA	NA	NA	NA
Barberg et al., 2007b	SD	7.8	NA	25.1	1	27.7	325,000	3.04	2.66	NA	20.9
Fulwider et al., 2007	SD	NA	NA	0	0	NA	176,700	NA	NA	21.1	20.4
Shane et al., 2010	SD	NA	NA	19.6	0	NA	155,000	3.1	2.4	NA	NA
	CC	NA	NA	18.5	0	NA	123,000	3.2	2.7	NA	NA
	WC/SD	NA	NA	0	0	NA	175,000	3.3	2.5	NA	NA
	SS/SD	NA	NA	19.4	5.4	NA	111,000	3	2.9	NA	NA
	WC/SS	NA	NA	37.5	0	NA	282,000	3.3	2.6	NA	NA
	SS	NA	NA	46.9	3.1	NA	145,000	3	2.8	NA	NA
Klaas et al., 2010	NO	NA	NA	0	NA	NA	192,000	NA	NA	51.2	NA
Ouweltjes and Smolders, 2014[12]	WC	NA	NA	NA	NA	NA	NA	3.1	NA	NA	37.8
	GC	NA	NA	NA	NA	NA	NA	2.9	NA	NA	25.1
	GC	NA	NA	NA	NA	NA	NA	3.1	NA	NA	32.1

[1]SD = sawdust; CC = corn cobs; WC/SD = wood chip fines/sawdust (as mixtures on a 2:1 v/v ratio); SS/SD = soybean straw/sawdust (as mixtures on a 2:1 v/v ratio); WC/SS = wood chip fines/soybean straw (as mixtures on a 2:1 v/v ratio); SS = soybean straw; GC= green waste compost; NO=no bedding.

[2]Cows were evaluated for lameness using a 5-point scale (where 1 = normal and 5 = severely lame), lameness prevalence was calculated as the number of animals with locomotion score $\geq$3 divided by the total number of animals scored.

[3]Severe lameness prevalence was calculated as the number of animals with locomotion score $\geq$4 divided by the total number of animals scored.

[4]Hock lesions were classified using a 3-point scale (where 1 = no lesion, 2 = hair loss, and 3 = swollen hock with or without hair loss), hock lesion prevalence was calculated as number of cows with hock lesion $\geq$ 2 divided by the total number of animals scored

[5]Severe hock lesion prevalence was calculated as number of cows with hock lesion = 3 divided by the total number of animals scored

[6]Mastitis infection prevalence was calculated by the number of animals with a test SCC >200,000 cells/mL divided by the total number of animals.

[7]Body condition score. Animals were scored for body condition using a 5-point scale (where 1 = emaciated and 5 = obese)

[8]Hygiene scores were assessed using a 5-point scale (Where 1 = clean and 5 = very dirty) exept for Black et al., 2013 who used a 4-point scale (where where 1 = clean and 4 = filthy)

[9]Dirty cows prevalence was calculated by the number of animals with an hygiene score of $\geq$ 3 divided by the total number of animals scored.

[10]Annual herd turnover rate was calculated as the number of animals that died or were sold on the farm for the entire year divided by the average herd size.

[11]Not available.

[12]Some data from Ouweltjes and Smolders, 2014 and Ofner-Schröck et al., 2013 were omitted because of different methods used for cow scoring.

Table 1.2. Bacterial analises of bedded pack from CPB.

Reference	Bedding material[1]	Total Bacterial Count log10 cfu/g	Klebsiella log10 cfu/g	E. coli log10 cfu/g	Coliforms log10 cfu/g	Streptococci log10 cfu/g	Staphylococci log10 cfu/g	Bacillus spp. log10 cfu/g
Balck et al., 2014	SD	8.2	NA[2]	6.0	6.3[3]	7.2	7.9	7.6
Barberg et al., 2007a[4]	SD	7.0	NA	NA	6.0	6.6	6.2	6.5
Shane et al., 2010[4]	SD	7.4	5.9[5]	NA	6.8	6.9	4.4	6.9
	CC	7.8	5.8[5]	NA	6.6	7.5	6.0	7.4
	WC/SD	7.1	5.7[5]	NA	6.5	6.6	4.6	6.8
	SS/SD	7.1	5.1[5]	NA	6.4	6.7	4.1	6.6
	WC/SS	7.6	5.8[5]	NA	7.0	6.8	ND[6]	7.4
	SS	7.5	4.6[5]	NA	6.5	7.0	ND	7.3
Lobeck et al., 2012[4]	SD	6.5	2.4	NA	4.1	6.5	4.0	4.4
Driehuis et al., 2012	WC	8.4	5.6	2.4	NA	3.0	NA	NA

[1]SD = sawdust; CC = corn cobs; WC/SD = wood chip fines/sawdust (as mixtures on a 2:1 v/v ratio); SS/SD = soybean straw/sawdust (as mixtures on a 2:1 v/v ratio); WC/SS = wood chip fines/soybean straw (as mixtures on a 2:1 v/v ratio); SS = soybean straw.

[2]Not available.

[3]Do not include E. coli

[4]Data from Barberg et al. (2007a), Shane et al. (2010) and Lobeck et al. (2012) have been adapted from original text.

[5]Part of Coliforms

[6]Not detected

Table 1.3. Milk quality of cows housed in CPB

Reference	Bedding material[1]	SCC cells/mL	Milk fat %	Milk protein %	Coliforms cfu/mL	Non-ag Strept. cfu/mL	Staph. species cfu/mL	Staph. aureus cfu/mL
Balck et al., 2014	SD	246,500	NA[2]	NA	NA	NA	NA	NA
Barberg et al., 2007a	SD	325,000	3.88	3.21	NA	NA	NA	NA
Shane et al., 2010[3]	SD	155,000	3.36	3.30	50.1	8.6	6.3	0.1
	CC	123,000	3.17	3.16	1058.1	872.1	5.8	1.9
	WC/SD	175,000	3.32	3.23	102.7	33.4	2.9	0.0
	SS/SD	111,000	3.06	3.09	2.8	6.0	11.1	0.0
	WC/SS	282,000	3.15	3.21	65.4	138.1	26.9	5.7
	SS	145,000	3.08	3.15	85.1	8.0	12.7	0.1
Lobeck et al., 2011 and 2012	SD	434,000	NA	NA	406.8	878.4	52.6	3.6

[1]SD = sawdust; CC = corn cobs; WC/SD = wood chip fines/sawdust (as mixtures on a 2:1 v/v ratio); SS/SD = soybean straw/sawdust (as mixtures on a 2:1 v/v ratio); WC/SS = wood chip fines/soybean straw (as mixtures on a 2:1 v/v ratio); SS = soybean straw.

[2]Not available.

[3]Data from Shane et al. (2010) have been adapted from original text.

Table 1.4. Characteristichs of bedded pack from CPB.

Reference	Bedding material[1]	Pack depth cm	Temperature °C	Moisture %	pH	C:N	N[2] %	P[2] mg/kg	K[2] mg/kg
Balck et al., 2013	SD	0	10.5	56.1	NA[3]	26.7	1.70	4000	13,000
		10.2	32.3	NA	NA	NA	NA	NA	NA
		20.3	36.1	NA	NA	NA	NA	NA	NA
Barberg et al., 2007a	SD	15	42.5	52.7	8.4	21.4	2.45	3111	13,831
		30		56.7	8.6	17.6	2.69	3442	17,202
Shane et al., 2010	SD	15.2	28.0	60.9	8.68	37.1	1.3	1449	4857
		30.5	31.8	57.8	8.69	37.4	1.3		
	CC	15.2	38.1	46.7	7.97	29.1	1.6	1620	8053
		30.5	40.8	41.2	7.38	29.3	1.5		
	WC/SD	15.2	21.4	61.3	8.54	45.7	1.1	1050	3893
		30.5	22.6	59.5	8.67	49.3	1		
	SS/SD	15.2	24.7	60.2	8.58	25.8	1.6	1749	7080
		30.5	28.4	54.9	8.57	25.4	1.5		
	WC/SS	15.2	19.5	60.2	8.48	31.6	1.4	2690	10,463
		30.5	19.2	62.3	8.57	30	1.5		
	SS	15.2	13.1	60.3	8.58	22.8	1.6	2104	8196
		30.5	13.1	62.3	NA	NA	NA		
de Boer, 2014[4]	WC	0-40	NA	56.9	8.6	10.5	3.57	6589	44,084
	GC	0-40	NA	47.5	8.3	16.6	1.36	3924	12,933
	GC	0-40	NA	44.6	8.8	15.1	1.63	3773	23,646

[1]SD = sawdust; CC = corn cobs; WC/SD = wood chip fines/sawdust (as mixtures on a 2:1 v/v ratio); SS/SD = soybean straw/sawdust (as mixtures on a 2:1 v/v ratio); WC/SS = wood chip fines/soybean straw (as mixtures on a 2:1 v/v ratio); SS = soybean straw; GC= green waste compost.

[2]On a dry matter basis
[3]Not available.
[4]Data from de Boer (2014) have been adapted from original text.

CHAPTER TWO: CULTIVATED PACK BARNS IN ITALY

INTRODUCTION

In Italy, since 2006, use of CPB has spread; currently, there are around 50 CPB, mostly located in the Po Plain, northern Italy (Uberti, personal communication, 2012). Although in other countries this housing system has evolved mainly with the aim of improving the welfare of dairy cows (Barberg et al., 2007a; Klaas et al., 2010), in Italy it was initially developed to reduce the risk of mastitis in SY. Italian farmers soon saw the advantages in the CPB in terms of udder health (Vighi et al., 2009). A few years later, also the positive effects on cow comfort and lameness became evident, and many more farmers shifted to CPB. As a matter of fact, one of the most noticeable benefits of CPB regards cow comfort and feet and leg health (Barberg et al., 2007b; Fulwider et al., 2007; Klaas and Bjerg, 2011; Ofner-Schröck et al., 2013; Black et al., 2013). Although, in recent years, Italian dairy farmers have shown a growing interest in CPB (Ventura, 2011), there is still little scientific knowledge available about Italian type of CPB. The objective of the current study was to describe housing system and management practices, assess producers' satisfaction, and measure performance of dairy cows housed in CPB in Italy.

MATERIALS AND METHODS

This observational study was performed on 10 dairy farms in the provinces of Mantua (n=7) and Cremona (n=3), northern Italy. All farms included met the following criteria: shifted to CPB at least two years before the start of the study, all lactating cows were housed in CPB, the pack was cultivated at least once a day, the primary breed was Holstein, cows were milked twice daily in milking parlor, cows were fed with total mixed ration (TMR) based on corn silage.

Monthly dairy herd records were obtained from the Italian Dairy Association (Associazione Italiana Allevatori, Rome, Italy) for each farm included in the study. To assess herd performance, the following data were collected over a period of one year (from September 2011 to September 2012): herd mean daily milk yield; 305-day mature equivalent milk production (305ME); days in milk (DIM); fat and protein content; herd mean SCC; age at first calving; mean number of parity; calving interval; mean number of services per pregnancy. Each farm was visited once between July and September 2012 to collect on-site data that included: barn dimensions and layout, total available surface area per cow, lying surface area per cow, bedding type, and pack depth.

Barn dimensions were measured using a Leica DISTO A5 laser distance meter (Leica Geosystems, Heerburgg, Switzerland). A questionnaire was given to the herd manager at the time of the visit. The first part of the questionnaire included 25 questions regarding pack management practices, machinery and equipment used, labor required and consumption of bedding. In the second part of the questionnaire, producers were asked to express their satisfaction with the housing system with regards to animal welfare, cow cleanliness, udder health, claw and leg health, fertility, longevity, milk yield, ease of management, costs and manure management. Satisfaction levels was expressed using a 4-point scale (where 1=very dissatisfied, 2=dissatisfied, 3=satisfied and 4=very satisfied).

In addition, 5 farms were visited twice, once in winter (January 2012) and once in summer (August 2012), to measure the temperature of the pack and the air temperature inside the barn. Pack temperatures were taken at ten points across the resting area at a depth of 20 cm. Air temperature was measured in five positions inside the barn at 1 m above the pack surface. Temperature was measured by the same operator using a DO 9847 portable multifunction data-logger (Delta Ohm, Padua, Italy).

Statistical analysis

Descriptive statistics (mean, SD and range) were used to describe herd characteristics, surface area per cow, pack depth, pack temperatures, air temperatures, quantitative data regarding management practices, and producer satisfaction scores. Results are presented as mean±SD and range. Linear regression analyses were performed to identify variables affecting consumption of bedding and labor requirement. Residuals were visually checked. Coefficient of determination (R2) was calculated to assess the goodness of fit of the model and a t-test was performed to determine whether there is a significant linear relationship between variables. All analyses were performed using the Base and Stats packages of R (R Development Core Team, 2011).

RESULTS

Herds included in this study numbered 112±58.8 lactating cows (range 42-192). Descriptive statistics for the herd performance are reported in Table 2.1. All the barns had a flat concrete floor under the bedded pack and 9 barns had an indoor (n=6) or outdoor (n=3) scraped feed alley. Feed alleys were 4.32±1.54 m wide while the space per cow at the feed fence was 0.58±0.20 m/cow. One barn did not have a scraped alley. Total available surface area per cow was 11.0±4.1 m^2/cow. The resting area (compost-bedded pack) per cow was 6.8±2.2 m^2/cow (range 3.56-10.18 m^2/cow). At the moment of farm visits the bedded pack was 25.6±9.4 cm deep (range 15-40 cm).

Management

The most commonly used management practice applied in CPB in this study starts with preparation of a compost-bedded pack. To do this, a layer of 10-20 cm of organic bedding is distributed on the floor of the lying area. During the first 5-10 days, the pack is not aerated and no bedding is added. After this start period, the surface of the bedded pack is stirred on a regular basis once or twice daily while cows are being milked in the parlor. A layer of fresh dry bedding is added every 12±17 days. Most producers add a consistent amount of fresh dry materials only when the bedding particles start to adhere to the cows, but in some dairies a smaller amount is added more frequently, up to once daily. Over the year, the bedded pack area is completely cleaned out every 30±35 days (range 10-90 days) when the moisture content of the bedded pack exceeds a critical level at which cows start to sink deep into the pack and aeration becomes difficult.

In 6 farms, the pack was aerated once a day and twice a day in the remaining 4; average 1.4 aerations per day. Typically, a tractor provided with a tine cultivator was used to stir the bedded pack. Tractors used to cultivate the pack had 62±16.1 kW horsepower (range 37-88 kW). On average, the pack was aerated at a depth of 19±7.6 cm (range 10-30 cm). Stirring the pack required 41±47 min/day (range 5-150 min/day) and resultant productivity was 2610.9±2425.7 m^2/h (range 725-8006.5 m^2/h). All the operations related to compost-bedded pack management (start-up, aeration, adding bedding and barn cleaning) required 356±274 h/year (range 136-1002 h/year). A comparison of the annual labor requirement for pack management with the average number of cows housed in each barn showed that annual labor per cow was 4.2±2.1 h/cow/year (range 1.2-6.7 h/cow/year). Since the labor requirement for pack cultivation mainly depended on the surface area of the bedded pack, a significant relationship (R^2=0.505; P=0.048) was found between the surface area per cow and the annual labor requirement for pack management (Figure 2.1).

Bedding

In this study, dry sawdust and wood shavings (mainly from pine wood) were used for CPB bedding. Seven producers used only sawdust while 3 preferred a mixture of sawdust and wood shavings. During winter, one farmer tried to add a load of coconut fiber but he reported problems due to a rapid rise in moisture content that resulted in a consistent loss of structure. In warm periods, some producers successfully re-used sun-dried manure derived from CPB. The amount of fresh bedding materials needed was 875.2±469.7 m^3/year (range 575-1600 m^3/year). Annual bedding requirement compared with the bedded area surface and the number of cows housed in each barn was, respectively, 1.4±2.9 m^3/m^2*year (range 0.3-2.6 m^3/m^2*year) and 8.2±2.9 m^3/cow*year (range 3.2-13.4 m^3/cow*year).

The amount of bedding, the frequency with which it was added, and the time between complete pack renovations strongly depended on the season and weather conditions. In all farms in the study, the consumption of bedding was concentrated in the winter period when there was little evaporation of water from the pack due to low air temperature and high relative humidity. Most of the dairies did not add any bedding to the pack in the period between May and late September. Although climate plays a major role, also the bedded surface area per cow affected the amount of bedding needed in CPB. Increasing the bedded surface area meant a greater amount of bedding was used to start-up the pack. On the other hand, a larger surface area per cow meant consistently less bedding was needed during the subsequent phases. A tendency towards an inverse correlation (R^2=0.395; P=0.051) was found between the surface area per cow and the annual amount of bedding used per cow (Figure 2.2).

Pack temperature

Pack temperature measured in the summer was 29.6±3.7°C (range 24.2-33.4°C) while air temperature inside the barn was 29.3±1.6°C (range 27.3-31.4°C). In winter, pack temperature was 11.7±6.0°C (range 6.4-21.6°C) while air temperature was 4.4±1.9°C (range 2.3-7.2°C). Both in summer and in winter, pack temperatures were not high enough for a composting process to be identified. However, the difference between pack and air temperatures measured on some farms in winter seems to suggest that the pack was biologically active. Some farmers noticed a reduction in resting time during winter that was probably due to low pack temperature. In a few barns, especially during summer, pack temperature was lower than air temperature. This was probably due to the intense evaporation of water from the pack's surface.

Producers' satisfaction

Overall, farmers were satisfied with CPB. Almost all producers identified cow welfare and leg and feet health as the main benefits of this alternative housing system. High satisfaction levels were also found in terms of udder health, fertility and manure management. Many farmers spontaneously remarked on a reduced presence of flies in CPB, especially during the summer. Major concerns regarded ease of management and costs. Results of the survey on producers' satisfaction are summarized in Table 2.2.

DISCUSSION

Most of the farmers interviewed shifted from deep straw-bedded yard to compost-bedded pack to reduce mastitis; the satisfaction level with regards to this suggests the objective was achieved. In dairies involved in the current study, herd mean SCC was 354,000±121,100 cells/mL. Barberg et al. (2007b) reported a similar mean SCC of 325,000 cells/mL for 12 herds housed in CPB in Minnesota. In the same study, a reduction in mastitis infection rate was found in 6 out of 9 herds after shifting to CPB. In a survey carried out in Kentucky, herd mean SCC was 275,510 cells/mL (Black et al., 2013). In contrast, Lobeck et al. (2011) reported a higher mean SCC of 434,000 cells/mL in CPB located in the upper mid-west of the US. Furthermore, they compared welfare of dairy cows housed in CPB and free stall barns and found no significant difference in mastitis infection rate. Although udder health in CPB seems to be adequate, difficulties in keeping the pack dry could pose challenges in terms of cow cleanliness, especially during winter. Many authors emphasized that high hygiene standards at milking and proper management of the pack are essential for achieving high milk quality in this housing system (Barberg et al., 2007b; Janni et al., 2007; Black et al., 2013).

Producers interviewed in the current study were generally satisfied with the welfare of cows housed in CPB. Similarly, Minnesota dairy farmers identified animal welfare as the main reason to build a CPB (Barberg et al., 2007a) and increased cow comfort compared to free stalls was the most frequently cited benefit of this alternative housing system among dairy producers in Kentucky (Black et al., 2013). Experimental data confirmed that CPB have a positive impact on the welfare of dairy cows (Barberg et al., 2007b; Fulwider et al., 2007; Lobeck et al., 2011). However, many authors remarked that cost and availability of bedding could limit the use of CPB (Barberg et al., 2007a; Shane et al., 2010), an issue about which Italian producers have also quite clearly expressed their concern. In the CPB included in the current study, the annual amount of bedding used was 8.2 m^3/cow*year. Considering an average cost for dry sawdust of 18 €/m^3, the annual bedding cost was 148 €/cow*year. Janni et al. (2007) estimated an annual bedding consumption in Minnesota CPB of 19.6 m^3/cow*year and a total annual bedding cost of $181/cow*year. Although the annual cost for bedding was similar, the amount of bedding used in Italian CPB was significantly lower than that used in Minnesota.

Climate differences could partially explain the amount of bedding needed but pack management and barn characteristics are also to be considered.

Many Authors consider the space per cow as a key factor in CPB management (Klaas and Bjerg, 2011). Janni et al. (2007) recommended a minimum pack surface area per cow of 7.4 m^2/cow for a 540 kg animal. More recently, researchers from Kentucky suggested that the optimal surface area per cow ranges from 9.3 m^2/cow to 10.2 m^2/cow (Black et al., 2013). Considering only the bedded area, the space allocation in CPB included in the current study was 6.8±2.2 m^2/cow. Since an inverse relationship was found between the space per cow and the amount of bedding used per cow (Figure 2.2), increasing the space per cow should result in lower bedding consumption. In fact, considering only the barns that had over 8 m^2/cow (n=4), the average annual amount of bedding used and the annual cost for bedding were 3.0 m^3/cow/year and 54 €/cow/year, respectively. On the other hand, greater space per cow may result in an increase in labor requirement and in added costs for barn building. The productivity of pack stirring operations varied considerably among farms in the study (range 725-8006.5 m^2/h). Producers reported that shape and dimensions of the barn, as well as the presence of fences and gates, strongly affected the amount of time needed to stir the pack. Bedded areas with a regular shape minimized the time required to aerate the pack.

The space per cow and the shape of the bedded area can significantly affect the cost of CPB management. However, pack temperature should also be taken into account. The heat produced by the microbial activity within the pack increases water evaporation and thus reduces the amount of bedding needed to keep the pack dry (Janni et al., 2007). Smits and Aarnink (2009) calculated that the evaporation of water from bedding which is effectively composting is higher than that from a non-composting pack. Black et al. (2013) found that in Kentucky CPB the ideal pack temperature is between 43°C and 60°C. Nevertheless, high pack temperatures seem to be necessary only in CPB with relatively high animal density (7.5-12.5 m^2/cow) and in cold climates, especially during winter. In Israeli climatic conditions, providing each cow with a spa e of at least 15 m2 meant it was possible to keep the pack dry throughout the whole year, even though heat generation was limited (Klaas et al. 2010). In CPB in the current study, pack temperatures (winter: 11.7±6.0°C; summer: 29.6±3.7°C) and the bedded area per cow (6.8±2.2 m^2/cow) do not seem to be sufficient to allow adequate evaporation from the pack, especially during winter.

Low bacterial activity in the pack could be explained by high animal density that leads to excessive bedding moisture content and thus limits the growth of aerobic bacteria. In order to ensure that the heat produced in the pack is not lost, relatively high pack depth is needed. Experience in the Netherlands indicated that a layer of at least 50 cm is needed to avoid excessive heat dissipation during pack stirring (Galama et al., 2011). In addition, higher pack depth allows manure to be stored in the barn for longer periods of time, thus reducing the need for external storage and the labor required for pack renewal. In CPB in the current study, pack depth ranged from 15 cm to 40 cm. Most producers reported problems in increasing the pack depth because the bed moisture content increased too rapidly and cows sunk deep into it. Some farmers noticed a reduction in cow resting time during winter that is probably due to the excessive moisture and the low temperature of the pack. This is in contrast with behavioral data obtained in free stall barns where resting time is longer in winter than in summer (Barbari et al., 2012). In Italian CPB, lower animal densities seem to be needed to maintain adequate pack moisture content and reduce the amount of bedding required, especially in winter. Further studies are needed to identify the optimal space per cow, monitor gaseous emission from the pack, and develop management recommendations for CPB in Italian climatic conditions.

CONCLUSIONS

Compost-bedded pack barns, if properly managed, could represent an effective solution for housing dairy cows also in Italy. Producers identified animal welfare as the main benefit of this system and overall they appeared to be very satisfied. Nevertheless, concerns about the cost of bedding seem to suggest that pack management and barn characteristics have not yet been optimized. Results obtained in this survey confirmed that animal density is a key factor in compost-bedded pack barns.

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We wish to thank all the dairy producers involved in the study for their kind collaboration. We also thank the Associazione Italiana Allevatori and the APA of Mantua and Cremona for their important contribution in providing data.

Table 2.1. Descriptive statistics for the herds' performance between September 2011 and September 2012.

Parameter	Min	Mean(SD)	Max
Milk yield (kg/cow*day)	24.8	30.8 (3.05)	35.2
Days in milk (days)	184	209 (29.1)	273
305 mature equivalent milk production (kg)	9205	10,541 (667)	11458
Milk fat (%)	3.43	3.67 (0.17)	3.88
Milk protein (%)	3.33	3.48 (0.10)	3.62
SCC (cell*1000/mL)	132	354 (121.1)	548
Age at firs calving (months)	22	29 (4.0)	35
Number of parity	2.01	2.39 (0.26)	2.74
Calving interval (days)	395	450 (35)	494
Number of services per pregnancy	1.84	2.67 (0.47)	3.53

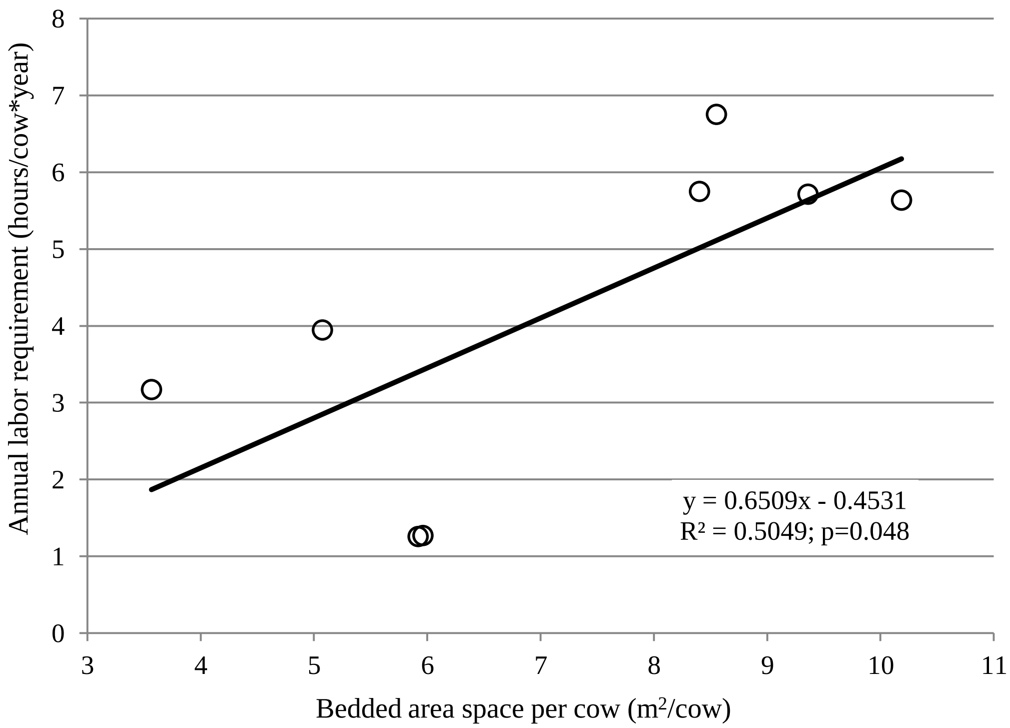

Figure 2.1. Scatter plot of the relationship between the bedded area space per cow and the annual labor requirement for pack management (data from 2 farms were not available).

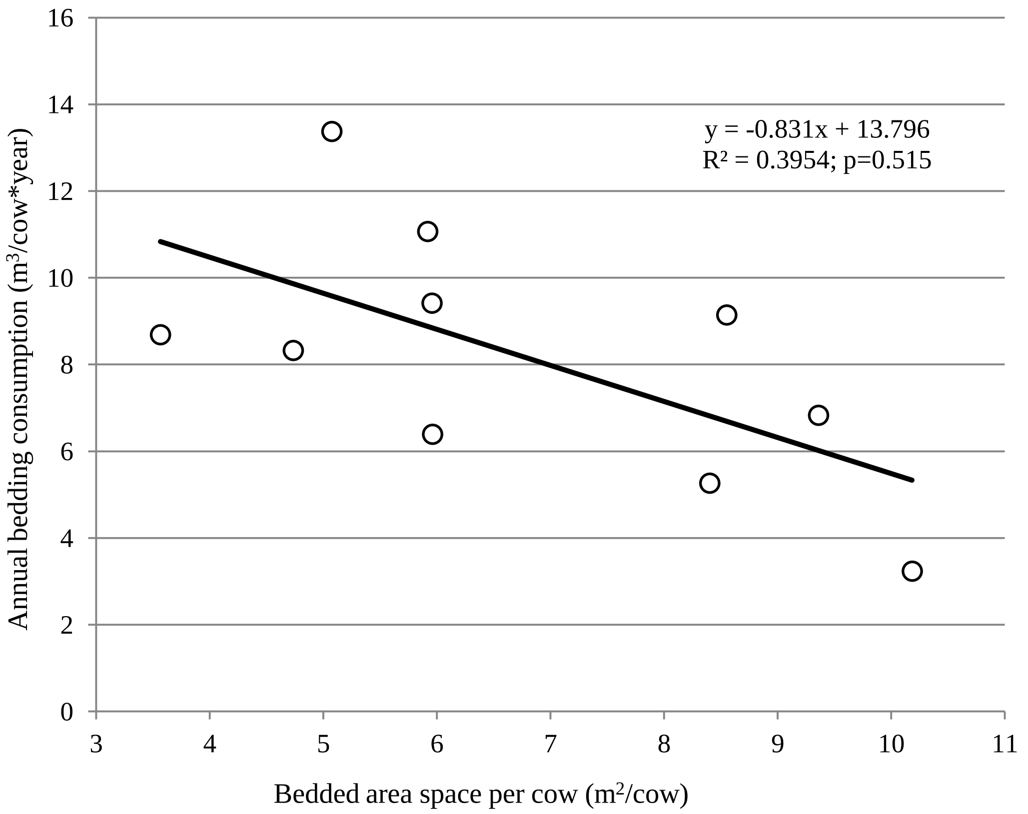

Figure 2.2. Scatter plot of the relationship between the bedded area space per cow and the annual amount of bedding used.

Table 2.2. Producers' satisfaction with compost-bedded pack housing system in regards to different issues.

Feature	Satisfaction level[a] Min	Mean	Max
Animal welfare	3	3,65	4
Cow cleanliness	2	3,00	4
Udder health	3	3,25	4
Claw and leg health	3	3,50	4
Fertility	2	3,13	4
Longevity	2	3,00	4
Milk yield	2	3,00	4
Ease of management	2	2,88	4
Costs	2	2,63	4
Manure management	2	3,25	4

[a]Satisfaction expressed on a 4-point scale (where1 = very dissatisfied and 4 = very satisfied).

CHAPTER THREE: PERFORMANCE AND LONGEVITY OF DAIRY COWS HOUSED IN FREE STALL AND CULTIVATED PACK BARNS

INTRODUCTION

The welfare of dairy cattle results from an interaction of several factors. Nevertheless, recent research shows that housing conditions and facility design play a major role in determining cow's health (von Keyserlingk et al., 2009). Free stall barns represent the most widespread housing system in intensive dairy farms worldwide. Despite recent many studies have shown this system can severely compromise animal welfare (EFSA, 2009). In the last few years, these welfare-related issues concerning FS have fostered the interest of farmers and researchers towards alternative loose housing systems, such as CPB. Since replacing cows on a dairy farm is a major cost of operation, the interest towards longevity as been fostered during the last years. Even though one of the main reasons producers reported for building CPB is improved cow comfort and longevity (Barberg et al., 2007b; Black et al., 2013), little is still known about the effect of this housing system on longevity. The objective of the current study was to evaluate and compare performance of dairy cows housed in CPB and free stall barns, with a particular interest in longevity-related parameters.

MATERIALS AND METHODS

This study was performed on 30 dairy farms in the provinces of Mantua (n=27) and Cremona (n=3), northern Italy. Twenty farms had FS, among which 10 used rubber mattresses (FSM) and 10 used straw bedding (FSS). The remaining 10 farms had CPB. Management practices applied in CPB included in this study were previously described in Chapter 2. All farms included met the following criteria: used the same housing system for all lactating cows for at least two year before the beginning of the study, the primary breed was Holstein, cows were milked twice daily in milking parlor, cows were fed with TMR based on corn silage.

Monthly dairy herd records were obtained from the Italian Dairy Association (Associazione Italiana Allevatori, Rome, Italy) for each farm included in the study. The following data were collected over a period of one year (from September 2011 till September 2012): number of cows, daily milk yield, 305ME, milk fat and protein content, SCC, number of parity, DIM, calving interval, no. of services per pregnancy, age at first calving and herd age. Herd age (HA) referred to the mean age (months) of all adult cows in the herd. Mastitis infection prevalence (MIP) was calculated as the number of cows infected divided by the total number of cows. Cows were considered to be infected when their test-day SCC was greater than 200,000 cells/mL.

For each farm the monthly herd turnover rate (MHTR) was calculated as the number of cows culled over a period of one month (x100) divided by the mean cow inventory for the same time period (Fetrow et al., 2006). The annual herd turnover rate (AHTR) was obtained by the sum of all the MHTR recorded over a period of one year. Monthly records were grouped by season (fall: September, October and November; winter: December, January and February; spring: March, April, May; summer: June, July and August). Each farm was visited once between July and September 2012 to collect on-site data that included: total available area, laying area (surface covered with bedding or mattresses), number of free stalls (only in free stall barns) and feed fence length. Barn dimensions were measured using a Leica DISTO A5 laser distance meter (Leica Geosystems, Heerbrugg, Switzerland). For each barn a bedded ratio (BR) was calculated by dividing the lying area by the total available area.

Statistical analysis

Descriptive statistics (mean and SD) were used to describe herds' performance and barns' characteristics in each group of farms with the same housing system. One-way ANOVA (R package "stats"; R Development Core Team, 2011) was used to determine whether housing system produces significant differences in space per cow, BR, number of cows, milk yield, 305ME, SCC, MIP, calving interval, number of services per pregnancy and AHTR. In order to evaluate the association between housing systems, herd records and the main outcome variables (HA and MHTR) a linear mixed model was built. An univariate linear model (R package “stats” ; R Development Core Team, 2011) was used to identify variables to be included in the multivariate model. Variables with P-value <0.2 were included. An automatic model selection procedure based on the R package "glmulti" (Calcagno and de Mazancourt, 2010; R Development Core Team, 2011) was used to build the models. The Bayesian Information Criterion was used for model selection. Variables included were all significant at P-value < 0.05. Housing system was forced in all models as explanatory variable. Residuals were visually checked. Tukey's method was used for multiple comparisons of least squares means (R package “lsmeans”; R Development Core Team, 2011) in categorically distributed variables within mixed models.

RESULTS AND DISCUSSION

Total available area per cow in CPB (11.0 ± 4.1 m^2/cow) was larger than that in FSM (9.0 ± 2.3 m^2/cow) and FSS (9.3 ± 5.4 m^2/cow; P<0.001). Cultivated pack barns had higher BR (0.65± 0.18) compared with FSM (0.38± 0.06) and FSS (0.37± 0.10; P<0.001). The pack density in CPB was 6.8± 2.4 m^2/cow. The characteristics of the barns are summarized in Table 3.1. The space per cow on the bedded area found in this study was lower than that measured in CPB in other countries. Barberg et al. (2007b) found an average pack density of 8.6± 2.6 m^2/cow in Minnesota CPB while Lobeck et al. (2011), studying CPB in the upper Midwest of US, measured an average pack density of 7.6± 1.1 m^2/cow .Other researchers from the University of Kentucky recommended that the pack area should provide at least 9.3 m^2 of resting space per cow (Bewley et al., 2013). Other experiences with CPB in the Netherlands found that at least 15 m^2 bedded pack space per cow is needed to keep the pack sufficiently dry for the whole year (Galama, 2014). Also in Israel 15 m^2/cow is considered to be an adequate pack density in CPB (Sprecher, 2013). Although the optimal space per cow in CPB depends on several factors such as climate, type and depth of bedding, barn's characteristics, pack management and type of cows (Klaas and Bjerg, 2011), the pack density found in Italian CPB (6.8± 2.4 m^2/cow) appears to be fairly too high for this housing system.

Characteristics and performance of the herds involved in this study are summarized in Table 3.2. The number of lactating cows was 143±83.9, 147±102.3 and 112±56.6 in FSS, FSM and CPB, respectively. Herds in CPB were smaller than those housed in FSS and FSM (P=0.004). Other studies from the US also found lower number of cows in CPB compared with free stall barns (Fulwider et al., 2007; Lobeck et al., 2011). Some authors reported an increased interest towards CPB for housing special need cows (Klaas and Bjerg, 2011). These findings led to think that although farmers have a positive perception of CPB, especially for welfare related issues, concerns about cost of bedding and ease of management could limit the use of this housing system in bigger operations (Lobeck et al., 2011).

Milk yield and 305ME did not differ among housing systems averaging 31.4±3.91 kg/cow*day and 10,901±963 kg, 29.8±4.6 kg/cow*day and 10,450±1043 kg, and 30.8±3.6 kg/cow*day and 10,541±663 kg in FSS, FSM and CPB, respectively. Somatic cell count in FSM (259,000± 115,000 cells/mL) was lower than that in FSS (310,000± 128,000 cells/mL) and CPB (354,000± 171,000 cells/mL) (P<0.001). Mastitis infection prevalence was lower in FSM (23.2± 8.4%) compared with FSS (29.6± 9.5%) and CPB (32.8± 12.7%) (P<0.001). The SCC measured in CPB involved in this study was similar to 325000 cell/mL (Barberg et al., 2007b) and 318,000 cell/mL (Black et al., 2013) previously reported in CPB located in Minnesota and Kentucky, respectively. Another research involving CPB in the upper Midwest of US found higher SCC (434,000 cells/mL) but similar MIP (33.4%). In the same study the udder health of cows housed in CPB was compared with that of cows in free stall barns finding that both SCC and MIP were lower in free stalls, even though differences were not statistically significant (Lobeck et al., 2011). These findings suggest that CPB could pose some challenges in achieving adequate udder health and high milk quality. Many authors emphasized the importance of excellent cow preparation procedures and high level of hygiene at milking in CPB farms (Klaas and Bjerg, 2011).

Calving interval was lower in FSS (420±19.1 days) compared with FSM (442±37.3 days) and CPB (449±72.9 days) (P<0.001). The number of services per pregnancy did not differ between FSS (2.54±0.61), FSM (2.59±0.64) and CPB (2.67±0.50). Since in CPB there was more space per cow and higher BR compared with free stall barns a more natural behavior could have been expected (Fulwider et al., 2007), thus may led to a easier heat detection. Barberg et al. (2007b) reported an increase in pregnancy rate in 5 out of 7 farms after shifting from tie stall to CPB. However, results obtained in the current study indicated poorer reproductive performance in CPB than in free stall barns. More exhaustive studies are needed to evaluate effects of this kind of housing system on reproductive performance whereas it is influenced by many environmental and management factors (Schefers et al., 2010).

Herd age and herd turnover rate

The final model for HA included housing system, calving interval and age at first calving. Herd age was higher in CPB (48.46 months) than in FSM and FSS (44.98 and 44.58 months, respectively; $P < 0.001$). No differences were found between FSM and FSS (Table 3.3). Each 1-day increase in calving interval was associated with a 0.044 months increase in HA. Herd age also increased with age at first calving by 0.381 months. In literature, information about the effect of CPB on HA or cows' lifespan are still lacking.

The final model for MHTR included housing system, season and housing system × season interaction. Monthly herd turnover rate was 2.98, 2.67 and 2.47% in FSS, FSM and CPB, respectively. No significant difference in MHTR were found between housing systems. Monthly herd turnover rate was higher in fall (3.69%) than in spring, summer and winter (2.38, 2.10 and 2.48%, respectively; $P < 0.001$). A housing system × season interaction was observed (Table 3.4). During fall, MHTR was lower in CPB than in FSS (P=0.036) while, during winter, CPB had lower MHTR than FSM (P=0.013). The FSS barns had higher MHTR in fall than in winter (P=0.002), spring (P=0.001) and summer (P=0,008). Monthly herd turnover rate in FSM was higher in fall than in spring (P=0.018) and summer (P=0.005) and it was higher in winter than in summer (P=0.027). No differences in MHTR were detected among seasons in CPB. This is in contrast to what would have been expected because in CPB the winter season is largely seen as a critical period due to difficulties in keeping the pack dry (Lobeck et al., 2011).

Annual herd turnover rate was 35.70±9.31, 32.37±6.59 and 29.68±11.00% in FSS, FSM and CPB, respectively. No significant differences were detected in AHTR among housing systems (P=0.352). This would be partially explained by the large variation in AHTR among farms. Lobeck et al. (2011) reported similar AHTR (30.1%) in CPB form US. In the same study, AHTR in CPB and free stall barns were compared and no significant differences between type of housing were found. Barberg et al. (2007b) reported sensibly lower herd turnover rate (20.9%) in CPB compared with that found in the current study. Within the dairy literature, the consensus is that lower AHTR are more profitable, with optimal rates of ≤30% (Fetrow et al., 2006). Annual herd turnover rates measured in CPB remained within this limit or barely above indicating that this alternative housing system can increase profitability of intensive dairy farms which often have higher culling rates. In a large survey carried out in the US including herds from 10 states over a 7-year period, the average culling rate was 35.1% (Hadley et al., 2006).

CONCLUSIONS

Cows housed in CPB were older than cows housed in free stall barns. Although, on average, the turnover rate was lower in CPB than in free stall barns no significant difference was found in turnover rate among housing system. This would be partially explained by the large variation in turnover rate among farms. Results obtained partially confirm that CPB may improve longevity of dairy cows, which is reported to be one of the most important motivations for building this kind of housing. Further researches are needed to obtain more consistent results, especially about culling rates.

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We wish to thank all the dairy producers involved in the study for their kind collaboration. We also thank the Associazione Italiana Allevatori and the APA of Mantua and Cremona for their important contribution in providing data.

Table 3.1. Characteristics of free stall barns with straw bedding (FSS), free stall barns with mattresses (FSM) and cultivated pack barns (CPB) in Italy.

	FSS		FSM		CPB	
	Mean	SD	Mean	SD	Mean	SD
Total area per cow (m^2/cow)	9.3	5.4	9.0	2.3	11.0	4.1
Stocking density (cows/stall)	1.09	0.42	0.92	0.10	-	-
Pack density (m^2/cow)	-	-	-	-	6.8	2.4
Bedded ratio	0.37	0.10	0.38	0.06	0.65	0.18
Space at feed fence (m/cow)	0.63	0.18	0.66	0.07	0.58	0.20

Table 3.2. Characteristics and performance of cows housed in free stall barns with straw bedding (FSS), free stall barns with mattresses (FSM) and cultivated pack barns (CPB) in Italy.

	FSS		FSM		CPB	
	Mean	SD	Mean	SD	Mean	SD
Cows, no.	143	83.9	147	102.3	112	56.6
Day in milk (days)	190	26.3	204	35.7	209	33.1
Parity	2.23	0.27	2.18	0.11	2.39	0.25
Milk yield (kg/cow*day)	31.4	3.91	29.8	4.6	30.8	3.6
305ME (kg) [1]	10901	963	10450	1043	10541	663
% fat	3.93	0.36	3.75	0.32	3.67	0.28
% protein	3.43	0.13	3.38	0.15	3.48	0.16
SCC (cells*1000/mL)	310	128	259	115	354	171
Calving interval (days)	420	19.1	442	37.3	449	72.9
Services per pregnancy, no.	2.54	0.61	2.59	0.64	2.67	0.50

[1]305ME= 305-days mature equivalent milk production.

Table 3.3. Least squares means and standard error of herd age in 3 housing systems: free stall barns with straw bedding (FSS), free stall barns with mattresses (FSM) and cultivated pack barns (CPB) in Italy.

Housing system	LSM	SE	
FSS	44.58[b]	0.34	
FSM	44.98[b]	0.33	
CPB	48.46[a]	0.33	
Other parameters	Estimate	SE	P-value
Calving interval (days)	0.044	0.007	<0.001
Age at first calving (months)	0.381	0.068	<0.001

[a,b]Significant among rows (P < 0.05).

Table 3.4. Least squares means and standard error of monthly herd turnover rate in 3 housing systems: free stall barns with straw bedding (FSS), free stall barns with mattresses (FSM) and cultivated pack barns (CPB) in Italy.

	Housing system					
	FSS		FSM		CPB	
Season	LSM	SE	LSM	SE	LSM	SE
Fall	4.41[a,x]	0.38	3.58[x]	0.38	3.08[b]	0.38
Winter	2.47[y]	0.38	3.26[a,x]	0.38	1.72[b]	0.38
Spring	2.38[y]	0.38	2.00[y]	0.38	2.76	0.38
Summer	2.47[y]	0.47	1.57[y]	0.47	2.47	0.47

[a,b]Significant differences among columns (housing systems) within season ($P < 0.05$).
[x,y]Significant differences among rows (seasons) within housing system ($P < 0.05$).

CHAPTER FOUR: THERMAL PERFORMANCE OF ALTERNATIVE BUILDING SOLUTIONS FOR DAIRY BARNS

INTRODUCTION

Heat stress in livestock housing is a major concern and, since the global temperature is likely to increase (IPCC, 2013), the magnitude of this issue will continue to grow. In dairy cows, heat stress can compromise milk production and reproductive performance, modify behavior, cause serious health problems and even lead animals to death (Jordan, 2003; West, 2003; Vitali et al., 2009; Tao and Dahl., 2013). In many cases, natural ventilation alone is not adequate to support the high production level of modern dairy cows (Berman et al., 1985; Armstrong, 1994). For this reason, several studies have been focused on active cooling techniques such as water sprinkling, forced ventilation and evaporative cooling even though their application considerably increases energy consumption (Ecim-Djuric and Topisirovic, 2010; Barbari et al., 2011; Legrand et al., 2011; Honig et al., 2012).

In the last years, significant efforts have been made to improve energy efficiency in the building sector. Researches on residential and commercial buildings showed that there are many passive solutions which can reduce the energy requirement for cooling purposes. The use of various types of plants as part of the building enclosure has been shown to improve its thermal performance (Saadatian et al., 2012; Pérez et al., 2014). Due to their capacity to intercept solar radiation, plants provide effective shade but, due to evapotranspiration, they also have an air-cooling effect (Jaffal et al., 2012). Both roofs and walls can be provided with vegetation. These techniques are commonly known as green roofs and green façades.

Green roof mainly refers to a roof covered with herbaceous and/or woody plants which are planted in a layer of soil or other growing medium. Many studies have been focused on thermal performance of these systems. In a literature review, Saadatian et al. (2013) found that green roofs can absorb 60% of the solar radiation and decrease the surface temperature of the roof up to 60°C, thus reduce the internal building temperature up to 20°C and the cooling load by 32 to 100%. In term of economics, green roofs can be an economical option in the long term but their initial cost is three to six times higher than a conventional roof (Blackhurst et al., 2010).

Green façades are vertical greenery systems that involve virtually any way to set plants in a building façade or wall. Traditionally, green façades consist of climbing plants or shrubs which grow directly along building walls or along supports such as frames and wires. In warm temperate climate, green façades can reduce the external surface temperature of the building façade wall from 12 to 20.8 °C in the summer period and from 5 to16 °C in autumn. This resulted in a reduction in energy consumption for cooling between 5% and 50% (Pérez et al., 2014).

Planting and growing trees near the building is another simple and effective means of reducing building solar loads and thermal regulation requirements in summer. Tree shade can decrease wall surface temperatures by up to 9°C and external air temperatures by up to 1°C (Berry et al., 2013). Balogun et al. (2014) found that tree shade sensibly lessens the energy requirement for cooling in a school building. Since greenery systems have the potential to improve the thermal performance of buildings and decrease the energy consumption for active cooling they could be profitably employed in dairy barns. However, literature about the use of these passive systems in livestock housing is almost lacking.

Another solution that has been spread in recent years is the use of greenhouse-type structure for livestock housing (Galama, 2011). Greenhouses typically have automatic vents and shading systems which appear to allow a better control over the internal microclimate compared with traditional shelters (Sethi and Sharma, 2007; Vanthoor et al., 2011). Moreover, greenhouses are considered to provide a more natural environment for the cows mainly because they allow improved natural lighting. Natural lighting also contributes in drying beddings and thus reduces the amount of bedding materials needed, especially during winter (den Hollander, 2014). In cultivated pack barns for dairy cows, winter is largely seen as a critical period for bedding management (Black et al., 2013). However, the use of greenhouses as housing for dairy cows is mostly spread in temperate areas with moderate summer temperatures. In warmer climates, the characteristics of the materials typically used for greenhouse cladding could pose challenges in keeping adequate internal temperature during summer months.

According to the information available, greenery systems for buildings and greenhouse-type structures can have a role in future development of housing systems for dairy cows. Although there are some issues concerning their employment, they have the potential to lower production costs, improve animal welfare and reduce environmental impact of dairy farming. Despite that, literature about the use of these solutions in dairy housing is still sparse. The aim of this study is to evaluate the effect on internal temperature of different roof configurations combining greenery systems and greenhouse-type coverings in warm weather conditions.

MATERIALS AND METHODS

The research was carried out by comparing the thermal performance of 6 different types of roof. Six identical reduced-scale buildings were fabricated (Figure 4.1). Each was 2 m long, 1 m wide and 1 m high. Experimental buildings had a wooden-frame structure made up of 40 x 40 mm timbers. Floor and curtain walls were built using 40 mm thick polystyrene sheets. To allow natural ventilation, a 1 m x 0.33 m opening was created in both two sidewalls of the experimental buildings. Since all the buildings were oriented with the ridge running East-West, the opening of the South sidewall was provided with a sloped overhang shading made up of a reflective cloth (ILS 70 F Revolux, Svennson, Kinna, Sweden). One of the six types of roof was applied to each experimental building.

The first type of roof was the reproduction of a gable roof with continuous ridge vent, which is a widespread solution for dairy barns in temperate climates. The covering consisted of sandwich panels (SAND) with 40mm-thick polyurethanic foam core and 2mm-thick aluminum skins. The thermal transmittance (U) of the panels used in SAND was 0.54 W/m^2*K (Isocop Granite, Isopan, Verona, Italy). To assess performance of different greenhouse-type roofs, 4 identical frame structure were assembled using 40x40 mm timbers. The structures reproduced the shape of a Venlo greenhouse with fixed continuous ridge vent. Each structure was provided with different covering materials and shading solutions. Two roofs were covered with a 0.2mm-thick transparent EVA film (PATILUX, P.A.T.I., Treviso, Italy) and two with a 0.2mm-thick EVA film which was specially developed to diffuse light in greenhouses (PATI DI LITE, P.A.T.I., Treviso, Italy).

The greenhouse-type roofs were equipped with different internal shading systems. The first consisted of a single shading screen with 70% shading level. The screen had an open structure to allow ventilation and its top surface was reflective (ILS 70 F Revolux, Svennson, Kinna, Sweden). The second shading solution was formed of a metal net which sustained climbing plants trained and tied to create a consistent layer. Eight potted Star Jasmine plants (*Trachelospermum jasminoides*) were used for each experimental roof. The pots had a capacity of 4 l each and were fixed to the metal net along the sidewalls of the experimental buildings. To keep the plants alive and physiologically active during the test, they were irrigated by an automatic drip system which was set to deliver 0.05 l/h in each pot.

To evaluate the shading level of the plant canopies, the leaf area index (LAI) was measured (Jonckheere et al., 2004). Ten plants were randomly selected among those available and the number of leaves per plant was counted. Twenty randomly selected leaves were plucked from all the plants available to evaluate their dimensions. To determine the leaf's area, length and width, a photo of leaves on graph paper was taken. Leaves were kept flat by placing a glass on them. The pictures were then imported in AutoCAD (Autodesk, San Rafael, California, USA) and scaled using the paper's grid as reference. The leaf's area was measured using a minimum of 20 points to better approximate the round perimeter. The LAI was calculated by multiplying the average one-sided leaf area by the average number of leaf per plant and by the number of plant used in each canopy. The value obtained was then divided by the internal area of each experimental building. The thickness of the plant canopies was measured in 5 randomly selected points in each building.

By combining the types of cladding and shading previously described, 4 different greenhouse-type roofs were obtained. Two of them had transparent EVA film covering, among which one was provided with the artificial shading screen (TRA+SHA) and one with the plant canopy (TRA+PLA). The remaining two greenhouse-type roofs had diffuse light EVA film covering, one with the artificial shading screen (DIF+SHA) and one with the plant canopy (DIF+PLA). In order to evaluate performance of the plant canopy alone, it was also applied to an experimental building which was not provided with covering (PLA). Cross sections of experimental buildings with different types of roof are reported in Figure 4.2.

Trials were carried out in Mantua (Italy) during August 2013 (13-27/08/2013). To avoid external source of shading, all the experimental buildings were placed in a field with no trees or constructions nearby and at a minimum distance of 4 m among them. In the experimental area, grass was mown before the beginning of the trials. During the whole experiment, dry bulb temperature was measured outside and inside the experimental buildings. The probe for external temperature was placed 1 m above the ground while those for internal measurements were placed inside each experimental buildings at 10cm above of the floor. The external probe was provided with a radiant screen. All the sensors used in the experiment were Pt100 resistance thermometers (DMA672-1, Lsi Lastem, Milan, Italy) and they were connected to a 16-bit data logger (E-log, Lsi Lastem, Milan, Italy). Both internal and external temperatures were recorded continuously every 15 minutes.

Data handling and statistical analysis

Since the experiment lasted 15 days, using data collected in the whole experimental period appeared to be the most logical choice. However, after first analyses it became evident that, due to the large amount of data (1440 records for each building), the power of main statistical tests was too high resulting in all differences being significant. Therefore, to reduce the size of the data set and minimize information loss, a single day which is representative of the whole experimental period (typical day) was identified. For each day, the sum of squared differences between the external temperature measured at every time of the day and the mean external temperature among all the days at the same time was calculated. The typical day had the lowest sum of squared differences. To better evaluate the effect of different types of roof on the internal temperature, data collected during the hottest and the coldest parts of the day were analyzed separately. Two distinct data set were built for the afternoon and for the night periods including data from 13:00 to 18:00 and from 01:00 to 06:00, respectively. By applying the same method used for typical day, a typical afternoon and a typical night were identified.

Multiple measurements within treatments cannot be considered as independent units of observations. Therefore, to assess whether different types of roof affected significantly internal temperature, repeated-measures ANOVA were performed on all data within typical day, typical afternoon and typical night with time of measurements as the repeated subject. Models were fitted using the ‘nlme' package of R while analyses of variance were carried out using the package ‘stat’ (R Development Core Team, 2011). Least squares means and SEM are reported for all data. To test pairwise comparisons between types of roof, posthoc analyses were carried out by Tukey test using the R package ‘multcomp’ (R Development Core).

RESULTS

During the whole experimental period (13-27/08/2013) weather was predominantly sunny. The average, maximum and minimum temperatures were 21.82, 33.95 and 10.05°C, respectively. These conditions can be considered representative of the summer period in the area where the experiment has been carried out (Mantua, Italy). Internal and external temperatures measured in the typical day, typical afternoon and typical night are shown in Table 4.1.

Plant canopy

On average, plants used in the present study (*Trachelospermum jasminoides*) had 484±91 leaves. Since the area of the experimental building was 2 m^2 and 8 plants were used in each canopy, the average leaf density was 1936 leaves/m^2. Leaves were 57±6 mm long and 19±4 mm wide. The one-sided area of a single leaf was 720±166 mm^2. On average, the LAI of the plant canopies used in this study was 1.39 m^2/m^2. The vegetation layer was 6.1±5.6 cm thick.

Typical day

The typical day was found to be the 23/08/2013. During that day the average external temperature was 21.85°C and the maximum and minimum temperatures were 30.64 and 13.80°C. Figure 4.3 shows external temperature and temperatures measured inside each experimental building during the typical day. Internal temperature was significantly affected by type of roof ($P<0.001$; Table 4.1). During daytime differences were more evident while during the night all the roofs produced similar internal temperatures. During the typical day, DIF+SHA and TRA+SHA had significantly higher temperatures compared with other roofs. Although DIF+SHA (22.69°C) had a higher temperature than TRA+SHA (22.50°C), no significant differences were found between them. Within the remaining 4 type of roof tested, TRA+PLA (21.63°C) had the highest temperature followed by SAND (21.50°C), DIF+PLA (21.43°C) and PLA (21.31°C) but they did not differ significantly.

Typical afternoon

The typical afternoon was on the 22/08/2013. In that period, which included the 5 hottest hours of the day (from 13:00 to 18:00), the average temperature was 28.45°C and the maximum and minimum temperatures were 29.47 and 27.48°C. External temperature and temperatures inside experimental buildings during the typical afternoon are shown in Figure 4.4. Type of roof had a significant effect on internal temperature ($P<0.001$; Table 4.1). As found in the typical day, DIF+SHA (32.00°C) and TRA+SHA (31.27°C) had significantly higher temperatures than other roofs but, in the typical afternoon, they differed significantly with DIF+SHA having a higher mean temperature. No significant difference were found among the remaining 4 roofs tough TRA+PLA (28.82°C) had the highest temperature followed by SAND (28.49°C), DIF+PLA (28.45°C) and PLA (28.35°C).

Typical night

The typical night was on the 11/08/2013. In that period, which included the 5 coldest hottest hours of the night (from 01:00 to 06:00), the average temperature was

16.51°C and the maximum and minimum temperatures were 17.36 and 15.15°C. Figure 4.5 shows external temperature and temperatures inside experimental buildings during the typical night. Type of roof had a significant effect on internal temperature ($P<0.001$; Table 4.1) even though, in the night period, differences were less marked than those observed in the daytime. Pairwise comparisons showed that TRA+PLA (16.40°C), DIF+PLA (16.36°C) and SAND (16.32°C) did not differ significantly but they had significantly higher temperatures than the other types of roof. No significant differences were also found among DIF+SHA (16.19°C), PLA (16.19°C) and TRA+SHA (16.15°C).

DISCUSSION

Among all the roof configurations tested, PLA had the best performance in terms of cooling capacity. Also TRA+PLA and DIF+PLA performed well, especially during the hottest part of the day. Except for the night period, temperatures inside the buildings with plant canopies (PLA, TRA+PLA and DIF+PLA) did not differ from that measured in SAND, even though they were not provided with any insulating material. These results confirm that plants have the capacity to effectively reduce the thermal load of buildings in hot weather conditions.

The type of greenery system used in this experiment was not properly a green roof nor a green façade since it was horizontal but there was not a continuous layer of growing medium on the roof (Saadatian et al., 2013; Pérez et al., 2014). For this reason, findings obtained in the present study cannot be directly compared with those reported in most of literature. Nevertheless, Koyama et al. (2014) used a similar greenery system. They examined a technique to cool a livestock building by covering its south wall and roof with kudzu vine (*Pueraria lobata*). Findings shown that the internal temperature of a building with 43.9% plant coverage was 3.44°C lower than that in a bare one. They also found that temperature reduction increased with the percentage of building covered.

In many researches regarding greenery systems for energy saving in buildings, characteristics of the vegetation, such as plant species, canopy density and fractional coverage, have been regarded as the most significant parameters affecting thermal performance (Dvorak and Volder, 2010; Cameron et al., 2014). In the present study, the percentage of the roof surface covered by plants was not measured directly. However, it can be considered to be almost fully covered, since canopies were specially prepared by tying plants to form a uniform and full layer. The LAI of the canopies was 1.39 that also indicates a complete covering, though many studies on green roofs and green façades reported higher LAI (Kumar and Kaushik, 2005; Hunter et al., 2014). Higher LAI are also typical for many other planted environments. In forests the maximum LAI varies from 6 to 8. In agricultural fields LAI varies from 2 to 4 for annual crops with a mean LAI for grassland of 2.5 (Asner et al., 2003) According to the information available, increasing LAI in greenery systems for energy saving in buildings would result in improved thermal performance (Jaffal et al., 2012).

In the typical day the experimental buildings with greenhouse-type coverings and shading net (DIF+SHA and TRA+SHA) had higher internal temperature than all other configurations tested, with differences ranging from 0.87 to 1.38°C (Table 4.1). During the hottest period of the day, these differences were even more noticeable (from 3.18 to 3.65°C for DIF+SHA and from 2.45 to 2.92 for TRA+SHA). This indicates that, in hot weather conditions, the use of conventional greenhouses for housing dairy cows may result in increased heat stress. However, it has to be considered that cladding materials used in this study (transparent and diffuse light EVA films) were not specifically developed to reduce the thermal load. Researches on greenhouse cooling techniques showed that by employing semi-transparent or reflective materials the internal temperature can be reduced (Kumar et al., 2009; Lamnatou and Chemisana, 2013). On the other hand, a semi-transparent cladding limit heat gain also during winter when, in the case of livestock housing, it is useful to dry the bedding and reduce consumption (den Hollander, 2014).

Results obtained in the present study shown that by providing greenhouses with plan canopies it is possible to obtain the same internal temperature as with traditional insulated coverings, even during hot weather. The plant tested (*Trachelospermum jasminoides*) was evergreen and it was selected for its wide availability and relatively low cost. However, using deciduous plants as shading in greenhouse-type dairy housing would allow to maintain an adequate temperature during summer and benefit from direct solar radiation during winter. The reduction in bedding consumption achieved could justify the higher initial and maintenance costs for greenery systems. In order to fully evaluate costs and benefits of this kind of housing systems for dairy cows, future studies should be carried out during a year round period. Furthermore, both deciduous and evergreen plants should be taken into account as well as semi-transparent cladding materials.

CONCLUSIONS

Greenery systems for energy saving in buildings and greenhouse-type structures can have a role in future development of housing systems for dairy cows. Results confirm that the employment of climbing plants as part of the building enclosure improves its thermal performance and has the potential to reduce energy consumption for cooling purposes. In hot weather conditions, greenhouse-type covering provided with plant canopies had the same internal temperature as an insulated roof. Compared with an artificial shading net, plant canopy produced a significantly lower internal temperature.

Figure 4.1. A picture of the experimental buildings taken during the tests.

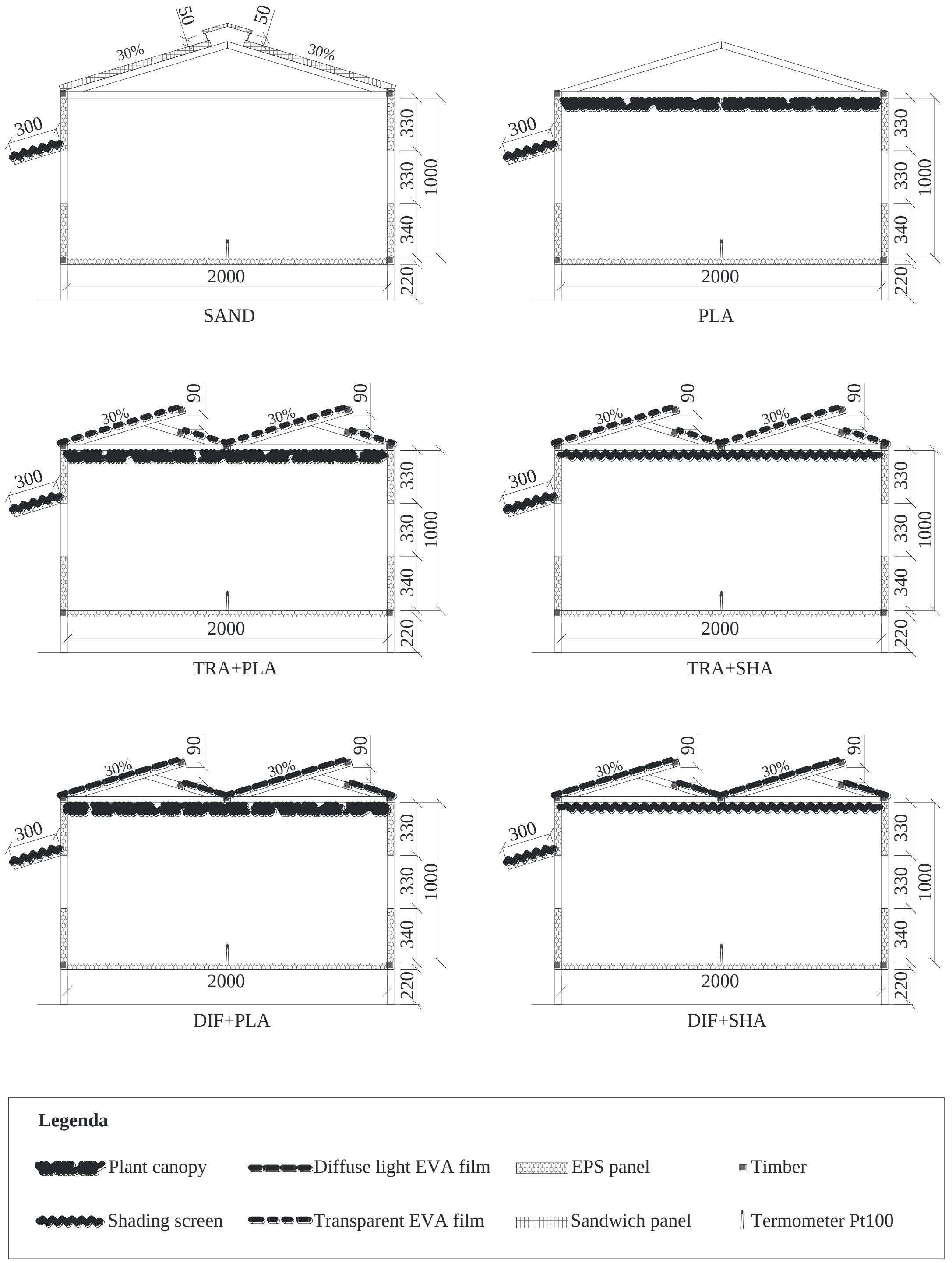

Figure 4.2. Cross sections of experimental buildings with different type of roofs: sandwich panels (SAND), transparent EVA film with reflective shading screen (TRA+SHA), diffuse light EVA film with reflective shading screen (DIF+SHA), transparent EVA film with plant canopy (TRA+PLA), diffuse light EVA film with plant canopy (DIF+PLA), plant canopy without coverings (PLA). Dimensions are expressed in mm.

Table 4.1. Last square means, SEM and significance of effects for internal temperatures in the experimental buildings with different types of roof during the typical day, typical afternoon and typical night.

		Treatments[2]							
Period[1]	External	SAND	TRA+SHA	DIF+SHA	TRA+PLA	DIF+PLA	PLA	SEM	Effect, P≤
Typical day, °C	21.85	21.50[a]	22.50[b]	22.69[b]	21.63[a]	21.43[a]	21.31[a]	0.626	0.001
Typical afternoon, °C	28.45	28.49[a]	31.27[b]	32.00[c]	28.82[a]	28.45[a]	28.35[a]	0.221	0.001
Typical night, °C	16.51	16.32[a]	16.15[b]	16.19[b]	16.40[a]	16.36[a]	16.19[b]	0.133	0.001

[a,b,c]Least square means in the same row with different superscripts differ ($P<0.05$).

[1]Typical day=23/08/2013 (whole day), typical afternoon= 22/08/2013 (from 13:00 to 16:00), typical afternoon= 11/08/2013 (from 01:00 to 06:00).

[2]SAND=Sandwich panels, TRA+SHA=transparent EVA film with reflective shading screen, DIF+SHA=diffuse light EVA film with reflective shading screen, TRA+PLA=transparent EVA film with plant canopy, DIF+PLA= diffuse light EVA film with plant canopy, PLA=plant canopy without coverings.

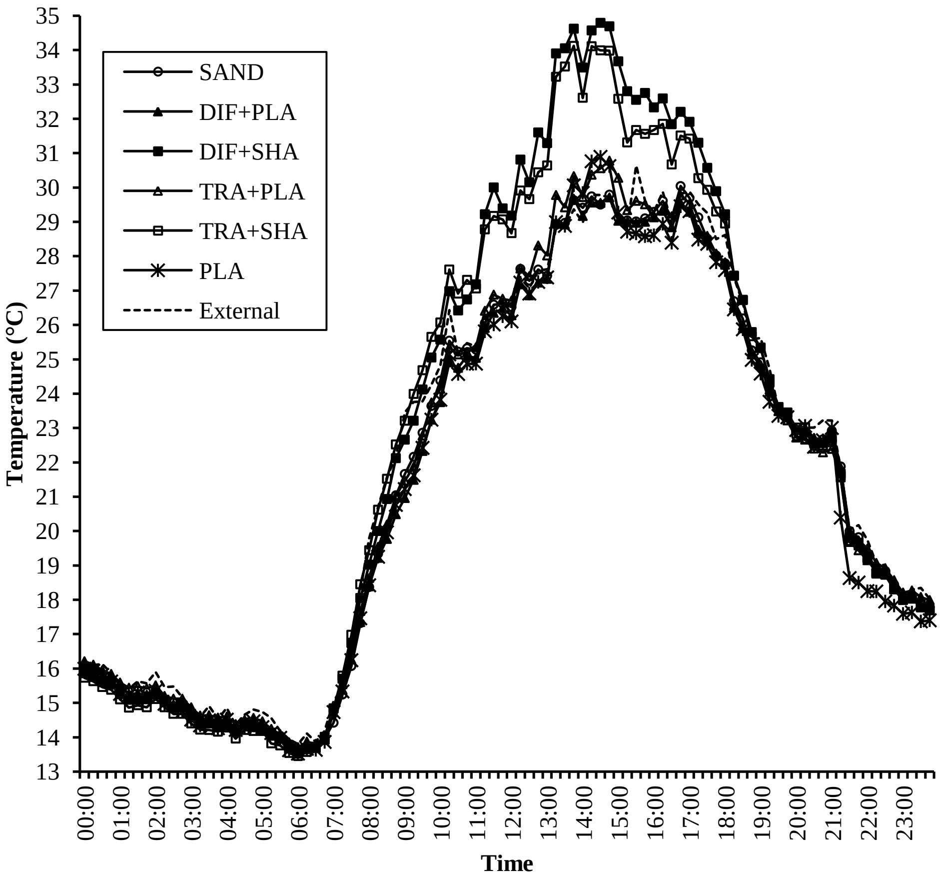

Figure 4.3. Variations in external temperature and temperatures measured during the typical day (23/08/2013) inside experimental buildings with different types of roof: sandwich panels (SAND), transparent EVA film with reflective shading screen (TRA+SHA), diffuse light EVA film with reflective shading screen (DIF+SHA), transparent EVA film with plant canopy (TRA+PLA), diffuse light EVA film with plant canopy (DIF+PLA), plant canopy without coverings (PLA).

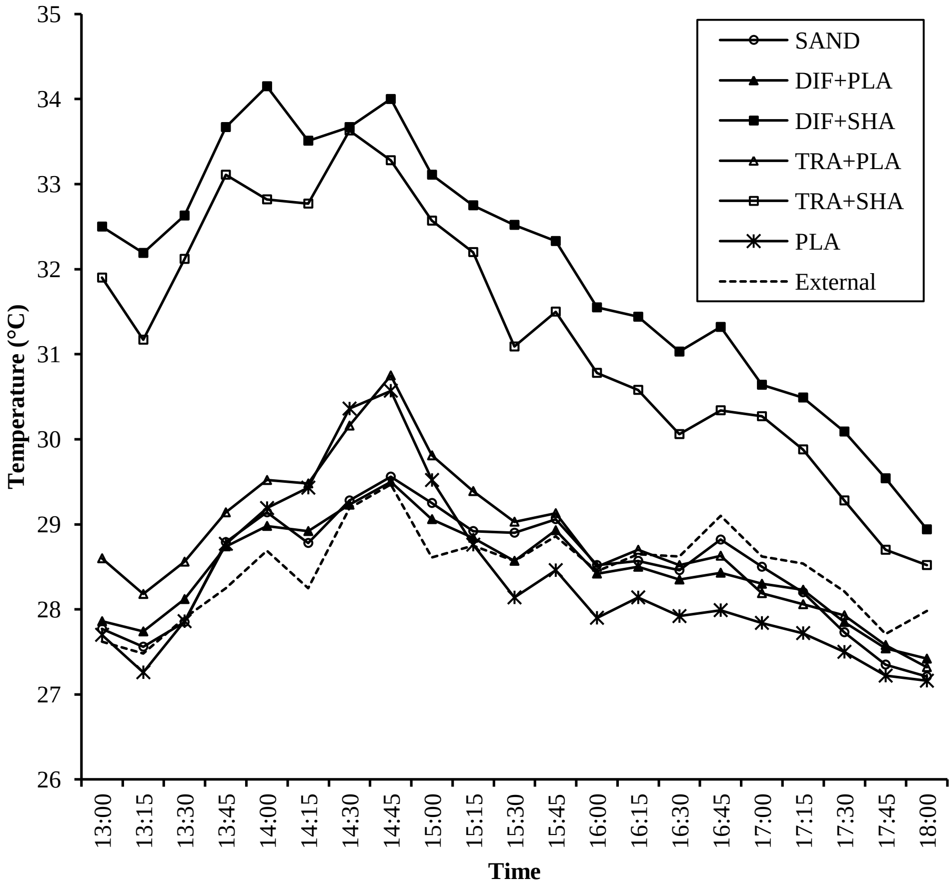

Figure 4.4. Variations in external temperature and temperatures measured during the typical afternoon (22/08/2013; from 13:00 to 18:00) inside experimental buildings with different types of roof: sandwich panels (SAND), transparent EVA film with reflective shading screen (TRA+SHA), diffuse light EVA film with reflective shading screen (DIF+SHA), transparent EVA film with plant canopy (TRA+PLA), diffuse light EVA film with plant canopy (DIF+PLA), plant canopy without coverings (PLA).

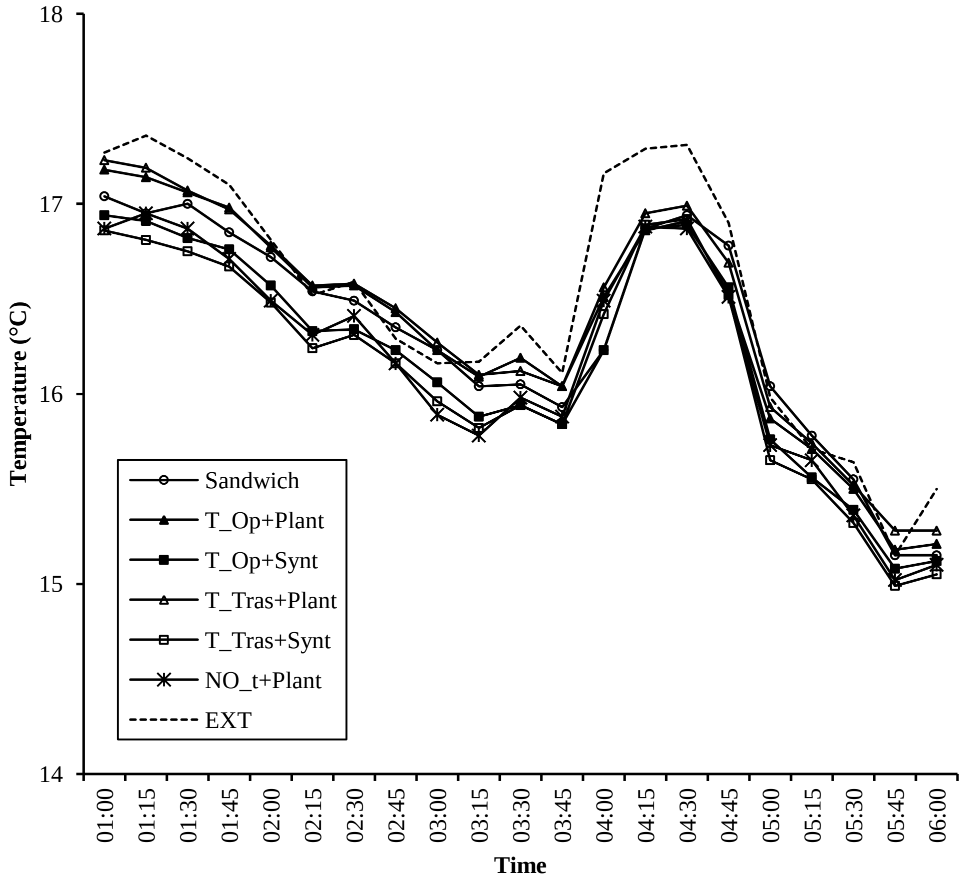

Figure 4.5. Variations in external temperature and temperatures measured during the typical night (11/08/2013; from 01:00 to 06:00) inside experimental buildings with different types of roof: sandwich panels (SAND), transparent EVA film with reflective shading screen (TRA+SHA), diffuse light EVA film with reflective shading screen (DIF+SHA), transparent EVA film with plant canopy (TRA+PLA), diffuse light EVA film with plant canopy (DIF+PLA), plant canopy without coverings (PLA).

CHAPTER FIVE: DESIGNING AN ALTERNATIVE HOUSING SYSTEM FOR DAIRY COWS IN HOT CLIMATE

INTRODUCTION

Housing can have major influence on animal welfare and operation profitability. The CPB housing system might improve cow comfort compared with FS. However, many different types of CPB have been developed worldwide and no standard solution is available for all farm, climate and economical context. Italian CPB system is quite different compared with those employed in other countries. Main differences regard space per cow and pack management. Though most Italian producers appear to be satisfied with their CPB (especially for animal welfare), some concerns about ease of management and bedding consumption have been reported. In almost all cases, Italian CPB were converted from SY and therefore facilities may not be adequate for this housing system. This Chapter aims at providing design recommendations for CPB in Italy based on information available in literature and experiences gained in existing barns.

SPACE ALLOWANCE

Space allowance has been identified as one of the most important parameters in CPB. However, no standard methods are available to estimate the best space per cow in CPB located in different regions, using different bedding materials, and applying different management strategies. Generally, composting packs (that produce heat) require less space allowance since heat development in the pack sensibly improves evaporation. Reduced space per cow might lessen barn's construction cost, however, information available in literature as well as farmers' experience indicate that maintaining the composting process in the pack may pose some challenges. The type of CPB developed in the upper mid-west of US (which is based on heat production in the pack) requires the lower space allowance (from 7.4 to 9.3 m^2/cow; Janni et al., 2007; Black et al., 2013) among all the solutions described in literature. Indeed, studies on American CPB reported relatively low construction costs (from $625 to $1750/cow place; Barberg et al., 2007a).

On the other hand, to support the composting process and keep the heat produced in the pack, a large amount of bedding material seems to be needed. As a matter of fact, in American CPB much more bedding per cow (19.6 m^3/cow*year; Janni et al., 2007) was consumed than in Italian CPB (8.2 m^3/cow*year; see Chapter Two), even though Italian barns had a lower space allowance (6.77 m^2/cow; see Chapter Two). Cost of bedding (especially sawdust and wood shavings) appears to be much lower in the US compared with Italy. This partially explains the differences in management and barn design approach between these two systems.

In Dutch CPB (with composting packs) the suggested space per cow is much higher (12 to 15 m^2/cow, Galama, 2014) compared with the American CPB systems. In Dutch CPB the bedding consumption (wood chips) is also high (8.4 ton/cow*year). To enhance the composting process and, in turn, heat development, a forced ventilation system has to be installed in the floor below the pack. This increases barn's construction cost. Dutch farmers reported that the forced ventilation system costs about 25-30 €/m^2 (Langennkamp and Hartman, personal communication, 2015). The construction cost of Dutch CPB (with composting pack) is indeed much higher (4309 €/cow place; Galama et al., 2014) than that reported for American CPB. Dutch experiences also indicated that, to keep the heat produced by the composting process in the pack, a minimum thickness of 50 cm is needed. This results in a relatively high cost for purchasing the bedding at the moment of pack's start up.

Since the development of heat in the pack improve evaporation, many authors identified composting process as a key factor in CPB management. Nevertheless, information available leads to think that maintaining an adequate composting process in CPB is somehow expensive, especially with high costs for wood materials. In most CPB systems based on heat production, wood materials (such as sawdust, wood shavings and wood chips) are used while other beddings that are commonly employed in other housing systems (such as straw) tend to be avoided. As a matter of fact, straw had lower pack temperature than other wood materials tested in American-type CPB (Shane et al., 2010). This indicates that with composting packs the choice of bedding materials is someway limited. Furthermore, high pack temperatures may lead to production of TAS and XTAS spores, which can impair milk quality. Most of the milk produced in Italian dairy farms is processed in to fresh and aged cheese. Even though TAS/XTAS spores should not compromise the quality of cheese (Driehuis, personal communication, 2014), no reliable data are available about the effect of TAS/XTAS on this kind of dairy products.

In the Italian context, CPB systems largely based on heat development in the pack does not appear be the best solution. However, since high pack temperature enhances evaporation, in CPB with no or limited composting process, larger space per cow is needed to keep bedding consumption at a reasonable level. Obviously, increased space allowance results in higher construction costs. For these reasons, to identify the optimal space allowance in CPB both bedding consumption and construction costs have to be considered. The optimal space per cow is that which minimizes both annual cost for purchased bedding materials and amortization of barn's initial cost. A model was implemented to identify the optimal space allowance for Italian CPB.

Bedding consumption vs. Space allowance

Data collected by surveying Italian CPB indicate that the annual consumption of bedding per cow is inversely related to the space per cow in the resting area (Figure 2.2). The following linear relationship was found:

$$B = -0.831 * S + 13.796 \qquad [5.1]$$

where:

B = annual bedding consumption (m^3/cow*year);

S = space per cow in the resting area (m^2/cow).

During many farm visits (especially during winter) the packs appeared too wet indicating poor management and need of fresh (dry) bedding. Therefore, in equation 5.1 the constant term was raised by 20%, resulting in the following equation:

$$B = -0.831 * S + 13.796 * 1.2 \quad [5.2]$$

According to equation 5.2, bedding consumption (B) might reach zero at a space allowance of 19.9 m^2/cow. However, even with a large space per cow, it is not possible to maintain adequate hygienic conditions without any bedding in Italian climate (especially during winter). Therefore, a lower limit was calculated for annual bedding consumption (B) as:

$$B_{min} = S * b_{min} \quad [5.3]$$

where:

B_{min} = minimum annual bedding consumption (m^3/cow*year);

S = space per cow in the resting area (m^2/cow);

b_{min} = minimum bedding consumption per unit of bedded area (m^3/m^2).

Minimum bedding consumption per unit of bedded area (b) was set at 0.3 m^3/m^2, assuming that a depth of at least 30 cm of bedding has to be used throughout the cold period (a 10 cm thick layer after barn cleanout in early winter and four bedding additions of 5 cm depth during winter and early spring). The minimum bedding consumption per unit area (b) is consistent with findings obtained in the survey on Italian CPB (see Chapter Two). Annual cost for purchasing bedding was calculated as:

$$C_{bed} = B * c_{bed} \quad [5.4]$$

where:

C_{bed} = annual cost of bedding (€/cow*year);

B = annual bedding consumption (m^3/cow*year);

c_{bed} = unitary cost of bedding (€/m^3).

In January 2015 some farmers (n. 5) with CPB and companies (n.4) that usually provide them beddings were interviewed to identify a mean price for sawdust, which is the most commonly used material. The mean cost of dry sawdust (delivered at the farm) was 20 €/m^3 (± 3.26 €/m^3).

Construction costs vs. Space allowance

Construction cost of the resting area (i.e. initial cost) per cow was calculated as:

$$C_{initial} = S * c_{constr} \qquad [5.5]$$

where:

$C_{initial}$ = construction cost of the resting area (€/cow);

S = space per cow in the resting area (m^2/cow);

c_{constr} = construction cost per unit area (€/m^2).

Construction cost per unit area was calculated on the basis of costs reported in the last reference price list issued by the Region Emilia-Romagna (2008). Construction costs for the resting area included earthworks, foundations (concrete plinths), structural frame (structural steel I-beams, dual pitched roof with ridge vent), roofing (40 mm thick sandwich panels), and floor (200 mm thick concrete floor with rebar net). Impermeable floor below the bedded areas is compulsory in Italy. The total cost per unit area (c_{constr}) was 150.03 €/m^2. The annual cost (annual payment amount) for construction of the resting area was calculated as:

$$C_{constr} = C_{initial} \frac{i(1+i)^n}{(1+i)^n - 1} \qquad [5.6]$$

where:

C_{constr} = annual payment amount for construction of the resting area (€/cow*year);

$C_{initial}$ = construction cost of the resting area (€/cow);

i = interest rate;

n= total number of payments (years).

Interest rate (i) was set at 3% while the duration of the payment period or total number of payments (n) was assumed to be 15 years, which is the expected lifespan of the building before extraordinary maintenance is needed.

Identifying the optimal space allowance

The total annual cost for the resting area included both annual payment for the amortization of construction cost and annual cost of bedding:

$$C_{tot} = C_{bed} + C_{constr} \quad [5.7]$$

where:

C_{tot} = total annual cost for the resting area (€/cow*year);

C_{constr} = annual payment amount for construction of the resting area (€/cow*year);

C_{bed} = annual cost of bedding (€/cow*year).

According to the equations described above (from 5.1 to 5.7), the space per cow (S) that minimizes the total cost for the resting area (C_{tot}) was found by using the Solver tool of Excel (Microsoft Excel 2010, Microsoft, Seattle, Washington, US). A constraint was set for the annual consumption of bedding (B) to be higher or equal to the minimum annual consumption of bedding (B_{min}). Within this context, the optimal space per cow (S) was 14.64 m^2/cow. At this space allowance it was estimated a total annual cost (C_{tot}) of 271.78 €/cow*year. The initial cost for the construction of the resting area ($C_{initial}$) was 2196 €/cow while the annual payment for the amortization of construction cost (C_{constr}) was 183.95 €/cow*year. Annual consumption of bedding (B) was 4.39 m^3/cow*year (or 0.014 m^3/cow*day) and the annual cost for purchasing bedding (C_{bed}) was 87.83 €/cow*year (or 0.24 €/cow*day).

Model limitations and discussion

The model used to estimate the optimal space per cow is based on data recorded in existing CPB (provided with scraped feed alley) located in northern Italy (see Chapter Two). Therefore, its application is restricted to that particular context and may not work correctly for other types of CPB, with different management styles and different climates. This model has been developed for CPB systems that are not based on heat development in the pack. Especially during winter, pack management focuses on water absorption rather than on enhancing evaporation. Since bedding materials (especially sawdust) are quite expensive in Italy, this approach appears to be more cost effective compared with managing the pack to maintain a composting process. As a matter of fact bedding consumption in Italian CPB (with no or limited heat development in the pack) is sensibly lower than that in American and Dutch composting systems.

Black et al. (2013) found an average bedding consumption (dry sawdust or shavings) of 0.05 m^3/cow*day or 18.25 m^3/cow*day in Kentucky CPB with composting pack and an average space per cow in the resting area of about 9 m^2/cow (8.9 m^2/cow for barns without attached feeding alley and 9.2 m^2/cow for barns with attached feeding alley). They also reported that Kentucky producers paid $8.19 per m^3 of dry sawdust, so the cost of bedding was $0.35/cow per day or $127.75/cow per year. A composting CPB with the same characteristics in Italy would produce a much higher cost for purchasing sawdust of 1 €/cow per day or 365 €/cow per year. This cost would be more than double that measured in existing Italian CPB (164 €/cow *year) that had no composting and a quite low space per cow (6.8 m^2/cow). Annual cost of bedding for an American-type CPB would be more than four times the estimated cost of bedding (87.8 €/cow *year) for an Italian CPB with optimal space allowance (14.6 m^2/cow).

Although heat development may reduce space per cow and, in turn, the initial cost of the barn, the sensibly higher amount of bedding needed to maintain the composting process would result in a higher annual total cost. As a matter of fact, an Italian CPB with 9 m^2/cow would have a relatively low initial cost of 1350.27 €/cow (considering just the resting area), which results in an annual payment of 113.1 €/cow*year (loan duration of 15 years and 3% interest rate). However, considering both annual payment for barn’s amortization and cost of bedding, an American-type CPB with composting pack in Italy would produce a total cost of 478.1 €/cow*year, which is almost twice as high as the total cost estimated for a non-composting CPB with optimal space per cow (271.8 €/cow*year).

The Dutch composting CPB system appears to require even more bedding than the American one, leading to think that it could not be effectively employed in Italy. In this kind of housing system, wood chips are used as bedding instead of sawdust or wood shavings. Last data available about Dutch-type composting CPB indicated a bedding consumption of 8.4 ton/cow*year (Galama et al., 2014). A space allowance of at least 12 m^2/cow is needed and a forced aeration system has to be installed in the floor below the pack. For this kind of CPB, authors calculated an annual cost of bedding of 168 €/cow per year (Galama et al., 2014). Therefore, a unitary cost for wood chips of 20 €/ton was assumed, even though other Dutch studies (Galama, 2014) reported higher costs for the same material ranging from 35 to 45 €/ton.

Since wood chips are not used in Italian CPB no reliable data about the cost of this material at farm gate are available. However, Italian studies on forestry productions and utilization of wood chips for energy purposes indicated that the cost for wood chips range from about 40 to more than 100 €/ton depending on moisture content and energy price (Francescato et al., 2009). Assuming a unitary cost for wood chips of 40€/ton, a Dutch-type composting CPB in Italy would produce an annual bedding cost of 336 €/cow, which is much higher than both that measured in existing Italian CPB (146 €/cow*year) and that estimated for a non-composting CPB with optimal space per cow (87.8 €/cow*year). Moreover the relatively large space per cow and the need of employing a forced aeration system, which costs 25 €/m^2, would result in a relatively high initial cost for barn construction (2100 €/cow, considering only the resting area) and, in turn, in an annual payment for barn amortization of 175.9 €/cow*year (loan duration of 15 years and 3% interest rate). Therefore, a Dutch-type composting CPB in Italy would produce a very high total annual cost of 551.9 €/cow*year.

Comparison with CPB system based on heat development in the pack indicate that maintaining a composting process in Italian CPB would be too expensive, primarily because it would require a large amount of wood materials. Nevertheless, it has to be considered that composting CPB systems have been developed in countries with different climates and therefore direct comparisons have to be carefully interpreted. Since environmental conditions deeply affect evaporation, they may have a major impact on pack management and barn design. The model proposed to estimate bedding consumption and optimal space allowance in Italian CPB is based on an equation that was obtained regressing data from only 10 barns located in a relatively small area. Its reliability and field of application are therefore limited, especially because environmental conditions and pack characteristics cannot be modified. However the data collected in existing barns represent the most reliable information available so far to describe the relation between space allowance and bedding consumption.

A better and more comprehensive model to estimate the optimal space per cow in CPB (and provide recommendations about pack management) would be based on the water balance of the pack. To achieve it, water input and output of the pack have to be known or reliably estimated. Plenty of information is available in literature about the amount and the characteristics of cattle excreta that represent the main water input for the bedded pack, even though the organic matter degradation processes also release some water. Instead, the determination of water output (mainly evaporation) appears to be much more problematic. Two studies from the Netherlands and US (Smits and Aarnink, 2009; Black et al., 2013) have estimated the drying rate of the pack by using the same mass transfer equation (Bird et al., 1960):

$$DR = k(C_{pack} - C_{amb}) \quad [5.8]$$

where:

DR = drying rate (kg H_20/m^2*s);

k = overall mass transfer coefficient (m/s);

C_{pack} = air moisture concentration at the pack surface (kg of H_2O/m^3 of dry air);

C_{amb} = ambient air moisture concentration (kg of H_2O/m^3 of dry air).

Air moisture concentration (C_{amb}) can be easily estimated by knowing common environmental parameters (relative humidity, air temperature and barometric pressure). The air moisture concentration at the bed surface was determined using bed surface temperature measured in existing CPB and assuming 100% RH (Black et al., 2013). Authors used different methods to calculate the mass transfer coefficient (k). Black et al. (2013) calculated k by using an equation inferred from field measurements. They included air velocity (at the pack surface) and pack surface temperature. Besides air velocity and temperature, the model used by Smits and Aarnink (2009) comprised some pack physical characteristics such as particles dimensions and material porosity. Results obtained by employing these two models appear to be not completely consistent indicating that further research is needed to define a standard method to estimate pack drying rate in CPB.

BEDDING MATERIALS

A CPB system that is not based on heat development in the pack would allow more flexibility in the choice of bedding materials. Although the most commonly used material in Italian CPB is sawdust, some farmers are trying other types of bedding. The most promising appear to be coconut fiber, chopped straw, wheat bran, rice chaff, chopped corn stalks and separated manure solids. Some Dutch farmers are using straw and a material called “toemaak”, which is a mixture of peat and chopped reeds (Galama et al., 2011; Galama et al., 2014). More recently, also hay from natural Dutch wetlands has been tried (Galama, personal communication, 2015).

Flexibility in bedding choice may play an important role in determining the economic sustainability of CPB systems in the future. However, no or limited information is available about the use of most bedding materials in CPB. Their employment in commercial dairies should be preceded by scientific tests. As a matter of fact, some materials that have been widely used in dairy farms are known to increase the risk of intramammary infections. Fresh sawdust is recognized as a possible source of Klebsiella organisms (Newman and Kowalski, 1973) while straw likely increase the risk of *Streptococcus uberis* infections (Bramley, 1982).

Furthermore, most bedding materials have not been tested in CPB. That's especially the case of straw.

Conventional bedded pack barns that have been usually bedded with straw are known to increase the risk of mastitis (Peeler et al., 2000) and the prevalence of dirty cows (Fregonesi and Leaver, 2001). Nevertheless, in the last months some Dutch producers started to use straw in CPB with encouraging results. Galama et al., (2014) reported that cows housed in CPB bedded with straw had low SCC. It appears that (regardless of the type of bedding) frequent pack cultivations and larger space per cow might help achieve better udder health in CPB than in SY (Barberg et al., 2007b). In Italy, straw is largely available and reasonably priced and may represent a viable alternative to sawdust in CPB. Nevertheless, further research about alternative bedding materials for CPB is deserved. Model proposed to estimate optimal space per cow and consumption of bedding might not work correctly with materials different from sawdust.

BARN LAYOUT

In the following sections, design recommendations concerning a CPB for 100 cows (Holstein) are reported. The optimal space per cow in the resting area (14.6 m^2/cow) was estimated for CPB provided with a scraped (or slatted) feed alley. Therefore, the barn will have two different areas, an open pack resting area and an attached feed alley. The dimensions of the resting area have to be calculated on the basis of space allowance and feed bunk space. The width of the resting area (with attached feed alley) can be calculated as:

$$W_{rest} = \frac{S}{FB} \qquad [5.9]$$

where:

W_{rest} = width of the resting area (m);

S = space per cow in the resting area (m^2/cow);

FB = space per cow at the feed bunk (m/cow).

A feed bunk space (FB) of 0.75 m/cow is adequate for high yielding cows (CIGR, 1994). Assuming a space allowance (S) of 14.6 m^2/cow a width of the resting area (W_{rest}) of 19.46 m is obtained. To avoid obstacles in the bedded area that may hinder pack management operations, posts are placed along the sides of the resting area. A span length of 20 m (center distance) would allow an adequate net width of the bedded area. The width of the feed alley should allow for unrestricted cow circulation and prevent agonistic interactions. A 4 m width feed alley would provide enough space for the passage of two cows in opposite directions while another cow is eating at the feed fence.

Nevertheless, experiences gained in Dutch CPB (where bedding and feed alley are at the same level) indicate that cows tend to walk (and stand) on the bedding next to the feed alley instead of on concrete, leading to fast spoilage of that part of the bedded pack. To avoid it, some producers installed a series of gates that separate the bedded area and the feed alley. Gates can be alternatively opened and closed to change the position of passageways. This would allow a more uniform utilization of the resting area. On the other hand, steelworks are quite expensive and may hinder normal circulation of the cows in the barn and increase aggressive interactions. For this reason it was preferred to provide free access to the feeding area. In order to prevent pack spoilage and encourage cows to utilize the resting area uniformly, the width of the feed alley was increased to 5 m.

Gates could be eventually installed in situations where cows have to be collected or confined frequently in the feed alley. In most cases this occurs just rarely and could be done by using temporary solutions (such as ropes, chains or simply electric fences). As a matter of fact, most farmers perform daily pack management operations (mainly pack cultivation) when cows are in the milking parlor. Producers with milking robots usually cultivate the pack immediately after delivering feed, when most of the cows are at the fence. To allow the installation of curtains on both the sides of the barn and protect the ration from rain, the feed lane was entirely covered. Therefore, a third line of posts was placed at a distance of 4.5 m from the feed fence or at 10 m (center distance) from the post placed between the feed alley and the bedded pack.

Since each cow requires a feed bunk length of 0.75 m, a barn length of 75 m is needed for 100 cows. Post spacing (center distance) was set at 5 m. A plan of a CPB with the characteristics described above is reported in Figure 5.1. The resting area is 1471.6 m^2, which provide a space per cow of 14.7 m^2/cow. Feeding alley area is 375 m^2 or 3.75 m^2/cow, giving a total space available to the cows (including resting and feeding area) of 1846.6 m^2 or 18.5 m^2/cow. The entire barn is 30.2 m large and 75.2 m long, resulting in a total covered area of 2271 m^2 or 22.7 m^2/cow (excluding overhangs).

The number and the dimensions of water troughs in dairy barns have a major impact on cows performance. To meet water needs of high yielding dairy cows, water trough space of at least 0.1 m/cow has to be provided (CIGR, 1994). Seven water troughs, each 1.8 m long (effective watering length), were placed in the CPB proposed, resulting in a space of 0.126 m/cow. The position of water points in a CPB may affect the utilization of the different areas of the barn. One of the major risks in an open pack barn like CPB is that cows do not utilize the entire surface of the resting area uniformly, posing serious challenges in pack management. To encourage cows using the whole bedded area, two water points were placed along the sidewall opposite to the feed alley. The damage caused to the pack nearby the water troughs is much limited compared with the risk of non-uniform utilization of the resting area. The remaining five water troughs have been placed in the feed alley.

FLOORING

In dairy cows housing, the characteristics of the floor deeply affect animals' health and behavior, and thus may impair their performance (Somers et al., 2003). Several studies indicate that housing cattle on a bedded pack have positive effect on claw health. As a matter of fact, one of the most noticeable benefits of CPB is the reduced prevalence of lameness and leg lesions (Klaas and Bjerg, 2011). However, some farmers noticed that in CPB with no feed alley (the entire surface is bedded) claws tend to overgrow (Bima, personal communication, 2014). This is likely due to the lack of abrasive surfaces. Therefore, a hard floor (such as solid or slatted concrete) in the feed alley would help in maintaining regular claw growth and shape. The CPB proposed (Figure 5.1) was provided with a solid concrete feed alley. The floor has to be adequately grooved to prevent slippage and injuries. Feed alley was also provided with a manure scraper. Since in Italy an impermeable layer below the bedded areas is compulsory, a concrete floor was placed below the pack. The concrete floor also allows easy cleanout of the bedded area with normal farm machineries. To provide some storage for the bedding as well as flexibility in the amount of bedding provided at pack's start up, the floor’s level in the resting area was set at 0.3 m below that of the feed alley (Figure 5.2).

BUILDING

Greenhouse-type structures with transparent cladding are believed to improve evaporation of water from the pack (den Hollander, 2014). However, under Italian climate, this kind of solution may lead to increased heat stress during summer months compared with conventional buildings provided with insulated roof (see Chapter Four). Alternative shading systems such as plant canopies can sensibly reduce heat gain in greenhouses but they have a high initial cost and require maintenance. Further research on greenhouse-type structures for livestock housing seem to be needed before these kind of structures can be effectively employed in Italian commercial farms. For this reason, a conventional gable roof structure provided with 40 mm thick insulated sandwich panels was preferred. Structural frame (posts, beams and joists) consists of structural steel I-beam. Building plan, cross section and elevations of the proposed CPB are reported in Figures 5.1 and 5.2.

BARN ORIENTATION, SHADING AND VENTILATION

Building orientation affects ventilation and sunlight exposure of the barn. The ideal orientation depends on several factors. To maximize natural ventilation, barns should be oriented so the prevailing summer winds are perpendicular to the barn ridge (Gooch, 2008). Since wind direction is very site specific, an east-west orientation is generally preferred because it minimizes barn sunlight exposure.

Penetration of direct sunlight increases cow's thermal load and therefore has to be avoided, especially during summer. Nevertheless, in the case of CPB, the exposure of the pack surface during winter months may improve evaporation and reduce bedding consumption.

The roof shape and the dimensions of sidewalls in the CPB proposed have been designed to maximize ventilation in the resting area and to allow sunlight to reach the pack during winter. The barn is oriented with the ridge in the east-west direction and the asymmetrical shape of the roof results in two different side walls. The height of the south eave is 5.3 m. This large unobstructed side wall would allow sunlight exposure of the pack during winter, when the sun elevation angle is lower. In summer, due to the higher sun elevation, the exposure of the internal environment is limited. Nevertheless, to protect internal environment from direct light exposure (and excessive wind), sidewalls could be provided with curtains. Relative sun position among the year for northern Italy (45.1°N; 10.7°E) is reported in Figure 5.3.

Since side wall curtains may hinder natural ventilation, their use should be limited. By planting a row of trees along the south side of the barn it is possible to effectively shade the south opening without affecting ventilation. Furthermore, trees reduce air temperature and roof thermal load and thus would reduce internal temperature (Berry et al., 2013). The employment of deciduous plants allows shading and cooling the building during the hot season without hindering sunlight exposure in winter. Sun elevation angles among the year and sunlight exposure of the proposed CPB are reported in Figure 5.4. Sun position analysis shows that, providing a high and unobstructed opening on the south side of the barn, a considerable part of the pack is directly exposed to sunlight during winter. This would help in keeping the pack dry. During summer instead, the employment of shading plants effectively reduce sunlight exposure.

Although the wide side openings of the proposed CPB have been designed to maximize natural ventilation, the Italian warm summer weather make the employment of mechanical ventilation systems highly recommended. High-volume low-speed (HVLS) fans have spread rapidly in dairy farms during the last years. Although recent research showed that this kind of fans are less effective in reducing heat stress than conventional high-speed fans (Worley and Bernard, 2008), HVLS may represent a viable solution, especially in open pack barns. Positioning of HVLS fans in the proposed CPB is reported in Figure 5.5. The installation of four 7 m diameter HVLS fans would provide adequate ventilation. In cases of extreme heat stress an additional cooling system, such as water sprinklers, could be installed in the feed alley.

CONSTRUCTION COST

The estimation of construction costs for the proposed CPB is reported in Table 5.1. A total construction cost of 386,514.6 € was assessed. Considering 100 cows housed, the cost per cow place was 3865.1 €/cow (excluding, HVLS fans, manure scraper, plumbing and wiring works, and milking systems). Estimated construction cost of the proposed CPB is considerably higher than that reported for American CPB (from $625 to $1750/cow; Barberg et al., 2007a; Black et al., 2013) but lower than that reported for Dutch composting CPB (4309 €/cow; Galama et al., 2014). The cost of the proposed CPB is similar to that found for non-composting CPB in the Netherlands (3709 €/cow; Galama et al., 2014).

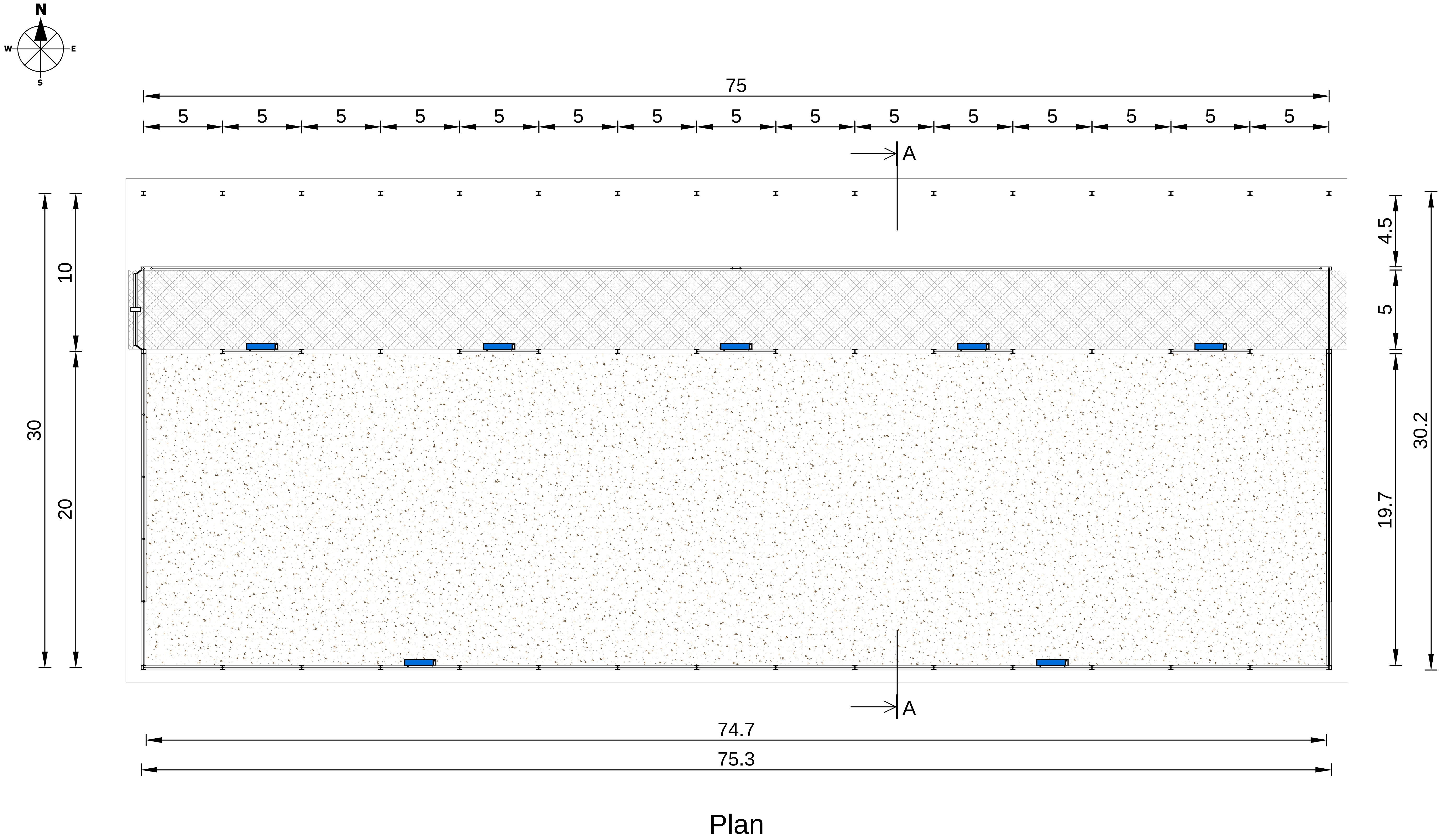

Figure 5.1. Plan view of the proposed cultivated pack barn for northern Italy climate. Designed to house 100 lactating cows (Holstein). Scale 1:250. Dimensions in meters.

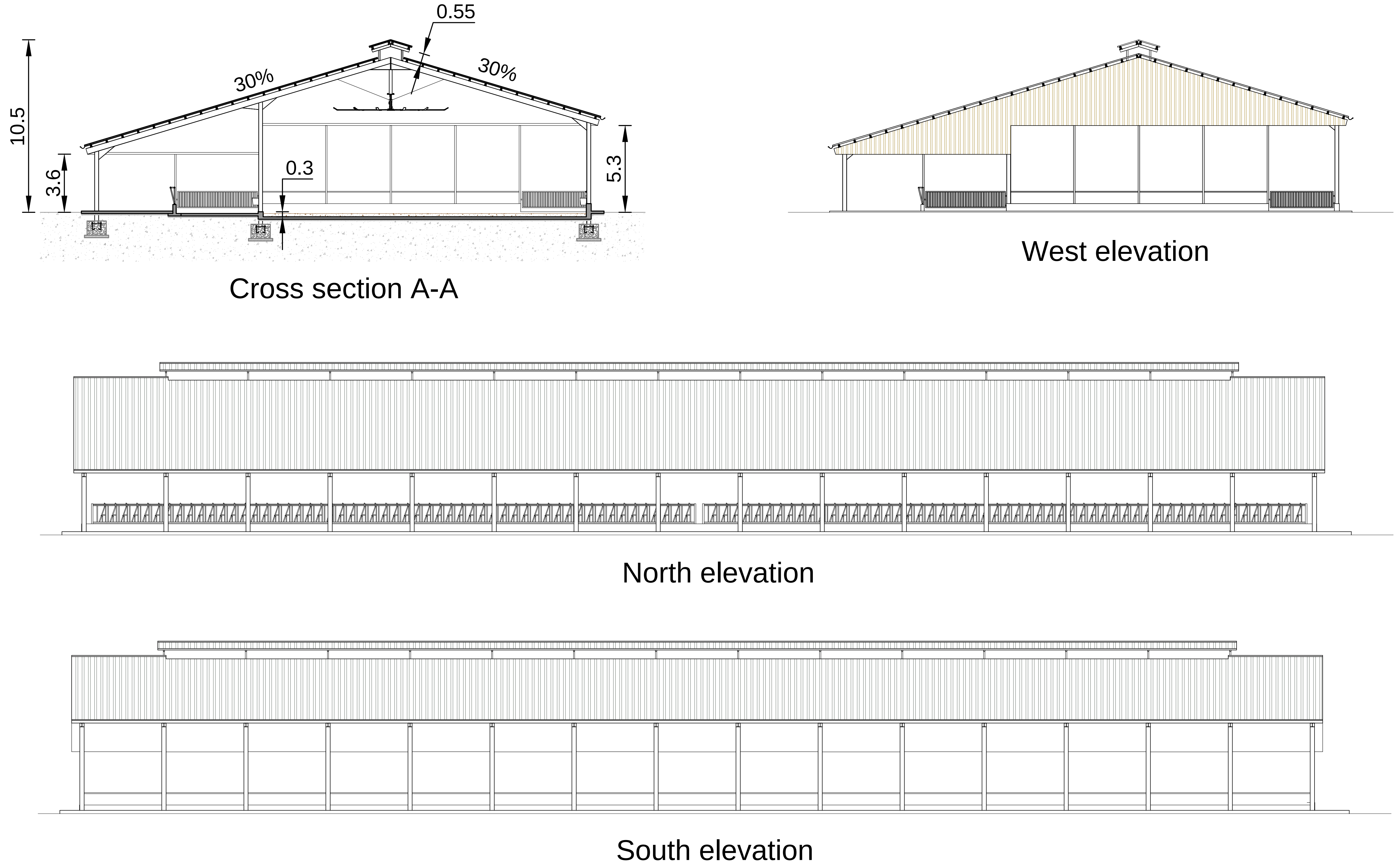

Figure 5.2. Cross section and elevations of the proposed cultivated pack barn for northern Italy climate. Designed to house 100 lactating cows (Holstein). Scale 1:250. Dimensions in meters.

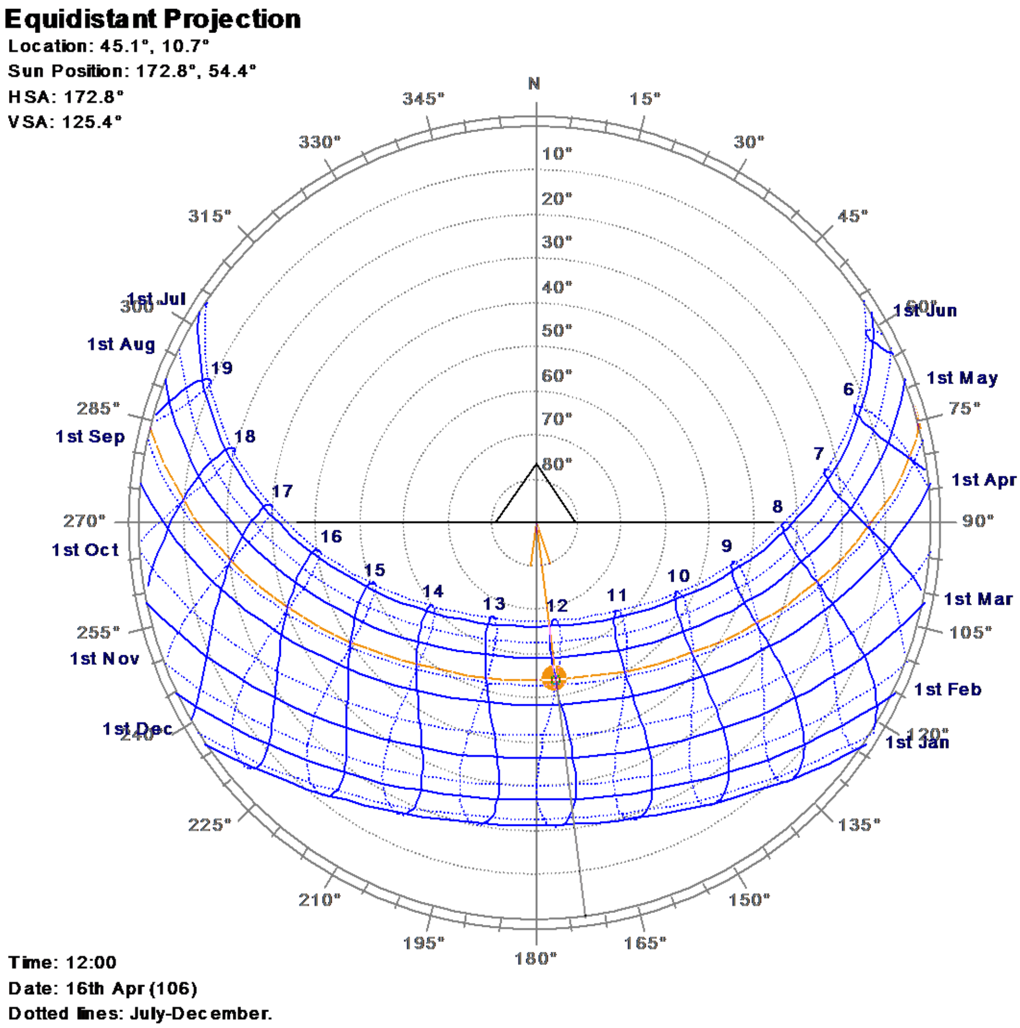

Figure 5.3. Sun position (equidistant projection) among the year for northern Italy (45.1°N;10.7°E).

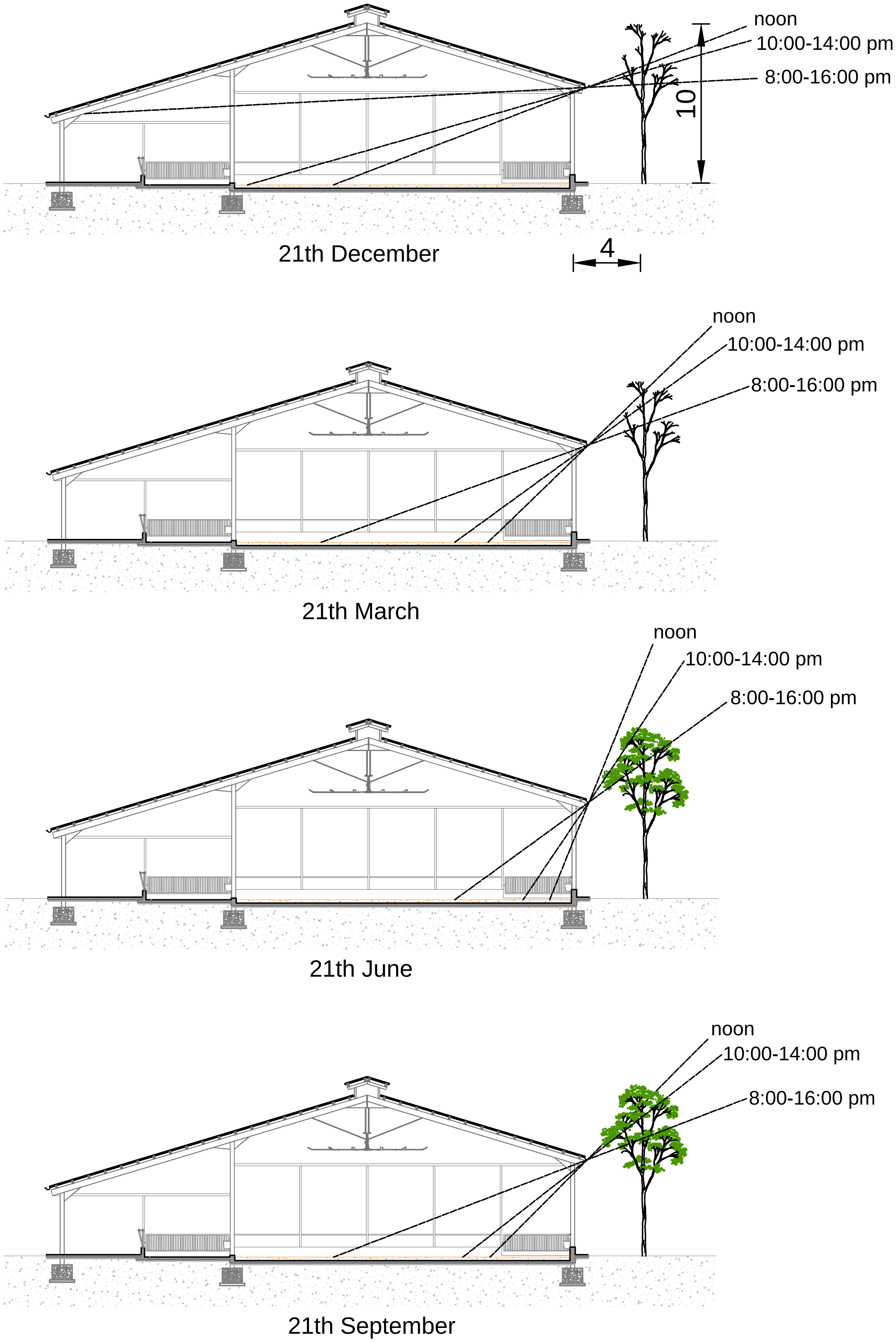

Figure 5.4. Sun angles on the proposed CPB for northern Italy climate provided with trees along the south side. Barn is located in northern Italy (47.1°N; 10.7°E) and is oriented with the ridge vent in the east-west direction. Not to scale.

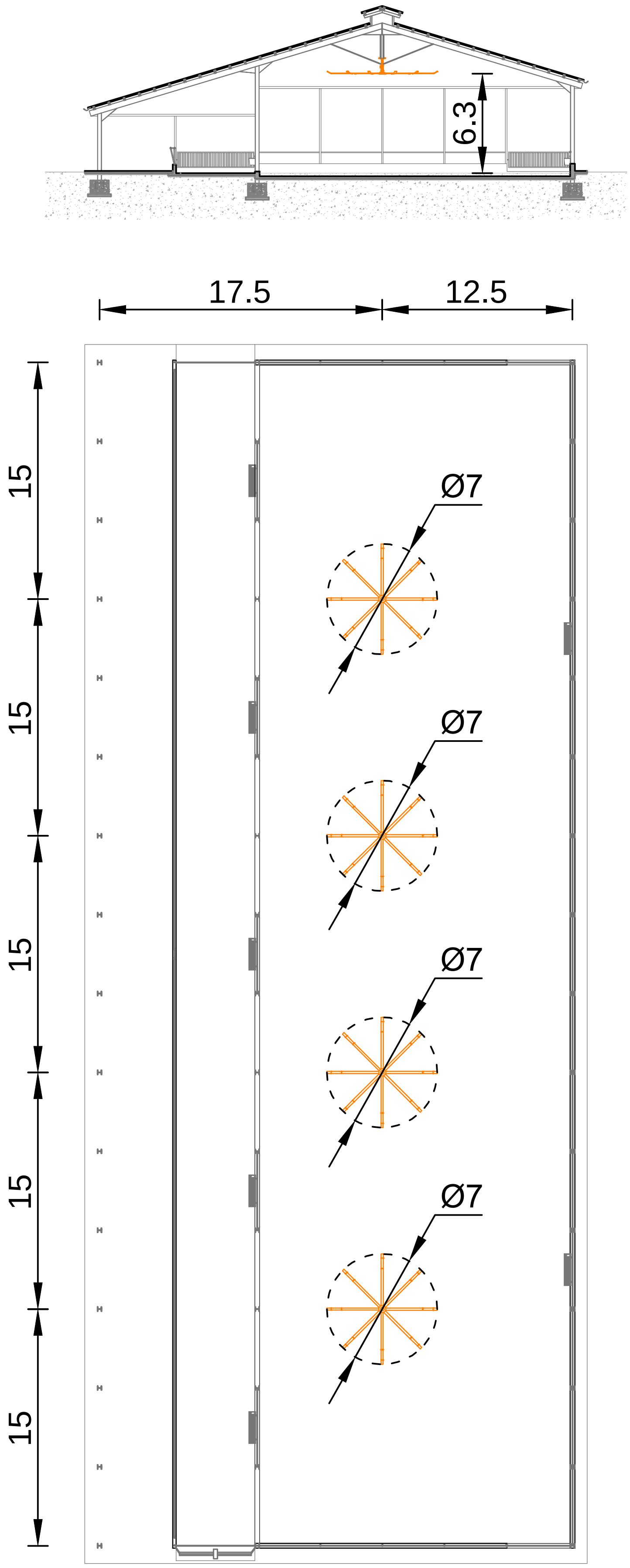

Figure 5.5. Layout of HVLS installation in the proposed cultivated pack barn for northern Italy climate. Designed to house 100 lactating cows (Holstein). Not to scale. Dimensions in meters.

Table 5.1. Cost assessment for the proposed CPB. Based on prices reported in the last official price list of the Region Emilia Romagna (2008).

	Cost/unit	Quantity	Cost
Earthworks (topsoil excavation, 0.5 m depth)	1.6 €/m^2	2450	3920 €
Foundations (precast concrete footing)	17.5 €/m^2	2270	39725 €
Superstructure (in structural steel I-beam, 128 kg/m^2 snow load, 70 kg/m^2 wind load)	60.5 €/m^2	2270	137335 €
Roofing (40 mm thick insulated sandwich panels)	26.2 €/m^2	2490	65238 €
Gable cladding (25 mm thick wooden boards)	28.4 €/m^2	146	4146.4 €
Floor (cast-in-place 220 mm thick concrete floor with rebar net)	44.2 €/m^2	2450	108290 €
Floor grooving (performed on green concrete with bullfloat provided with special grooving attachments)	3.4 €/m^2	385	1309 €
Side wall (cast-in-place reinforced concrete wall; 80 cm heigth, 20 cm thick)	41.2 €/m	107	4408.4 €
Manger wall (cast-in-place reinforced concrete wall; 50 cm heigth, 15 cm thick)	99.1 €/m	75	7432.5 €
Self-locking feed fence	93.4 €/m	75	7005 €
Partition barrier (galvanized steel, 4 rails)	44.9 €/m	25	1122.5 €
External barrier (galvanized steel, 1 rail)	25 €/m	107	2675 €
Gates (galvanized steel, 4 rails)	78 €/m	18	1404 €
Gates attachment plate	51.6 €/each	4	206.4 €
Water troughs (200 cm long)	328.2 €/each	7	2297.4 €
		Total construction cost	**386514.6** €

CONCLUSIONS

Results obtained in this research confirmed that CPB can represent a viable alternative to FS, especially because of improved cow welfare. Most Italian producers converted existing SY into CPB and therefore barns' characteristics are not completely adequate for this housing system. This is especially the case of space allowance, which has confirmed to be a key factor for CPB. On average, Italian producers allotted a very low space per cow of 6.8 m^2, resulting in a relatively high consumption of bedding. Nevertheless, overall producers appeared to be very satisfied with their CPB, especially for improved cow comfort. As a matter of fact, comparison with FS indicated that cows housed in CPB have improved longevity.

The assessment of greenhouse-type structure's thermal performance showed that conventional greenhouse shading systems may lead to increased heat stress for dairy cows, leading to think that these solutions are not adequate for Italian climate conditions. The employment of plant canopies as shading have shown to effectively reduce the thermal load of the building. Outcomes fostered the interest toward the applications of greenery systems in housing for dairy cows. However, before greenhouse-type structures can be effectively employed in Italian commercial dairy farms further research is deserved.

In Italian CPB, the temperature of the pack is much lower compared with that found in American and Dutch composting CPB. Although most authors highlighted the importance of heat development in the pack (to enhance evaporation), large amounts of bedding seem to be needed to maintain the composting process in CPB. Especially during winter, pack management in Italian CPB focuses on water absorption rather than on enhancing evaporation. Since bedding materials are quite expensive in Italy, this approach appears to be more cost effective compared with managing the pack to maintain a composting process. Nevertheless, large space per cow is needed to maintain bedding consumption at a reasonable level.

REFERENCES

Ahlman, T., B. Berglund, L. Rydhmer, and E. Strandberg. 2011. Culling reasons in organic and conventional dairy herds and genotype by environment interaction for longevity. Journal of Dairy Science. 94:1568–1575.

Alban, L. 1995. Lameness in Danish dairy cows; frequency and possible risk factors. Preventive Veterinary Medicine. 22:213–225.

Albright, J. C. 1995. Flooring in dairy cattle facilities. in Proceeding of the International Conference on Animal Behavior and the Design of Livestock and Poultry Systems, Indianapolis, IN.

Armstrong, D.V. 1994. Heat Stress Interaction with Shade and Cooling. Journal of Dairy Science. 77:2044–2050.

ASAE Standards. 2005. D384.2. Manure production and characteristics. St. Joseph, Michigan: ASAE.

Asner, G.P., J.M.O. Scurlock, and J.A. Hicke. 2003. Global synthesis of leaf area index observations: implications for ecological and remote sensing studies, Global Ecology and Biogeography. 12:191–205.

Astiz, S., F. Sebastian, O. Fargas, M. Fernández, and E. Calvet. 2014. Enhanced udder health and milk yield of dairy cattle on compost bedding systems during the dry period: A comparative study. Livestock Science. 159:161-164.

Balogun, A.A., T.E. Morakinyo, O.B. Adegun. 2014. Effect of tree-shading on energy demand of two similar buildings. Energy and Buildings. 81:305-315.

Barbari, M., L. Leso, G. Rossi, A. Scaramelli, and S. Simonini. 2012. Influence of cooling systems on the behaviour of dairy cows housed in cubicle barn. Journal of Agricultural Science and Technology. 1:40-49.

Barberg, A. E., M. I. Endres, and K. A. Janni. 2007a. Compost dairy barns in Minnesota: A descriptive study. Applied Engineering in Agriculture. 23:231–238.

Barberg, A. E., M. I. Endres, J. A. Salfer, and J. K. Reneau. 2007b. Performance and welfare of dairy cows in an alternative housing system in Minnesota. Journal of Dairy Science. 90:1575–1583.

Berman, A., Y. Folman, M. Kaim, M. Mamen, Z. Herz, D. Wolfenson, A. Arieli, and Y. Graber. 1985. Upper Critical Temperatures and Forced Ventilation Effects for High-Yielding Dairy Cows in a Subtropical Climate. Journal of Dairy Science. 68:1488–1495.

Bernardi, F., J. Fregonesi, C. Winckler, D.M. Veira, M.A.G. von Keyserlingk, and D.M. Weary. 2009. The stall-design paradox: Neck rails increase lameness but improve udder and stall hygiene. Journal of Dairy Science. 92:3074–3080.

Berry, R., S.J. Livesley, and L. Aye. 2013. Tree canopy shade impacts on solar irradiance received by building walls and their surface temperature. Building and Environment. 69:91-100.

Bewley, J., R. W. Palmer, and D. B. Jackson-Smith. 2001. An overview of experiences of Wisconsin Dairy Farmers who modernized their operations. Journal of Dairy Science. 84:717–729.

Bickert, W.G., and R.G. Light. 1982. Housing systems. Journal of Dairy Science. 65:502–508.

Bird, R. B., W. E. Stewart, and E. N. Lightfoot. 1960. Transport Phenomena. John Wily & Sons Inc., New York, NY.

Black, R. A., J. L. Taraba , G. B. Day , F. A. Damasceno , M. C. Newman , K. A. Akers , C. L. Wood ,K. J. McQuerry , and J. M. Bewley. 2014. The relationship between compost bedded pack performance, management, and bacterial counts. Journal of Dairy Science. 97:1–11.

Black, R. A., J. L. Taraba, G. B. Day, F. A. Damasceno , and J. M. Bewley. 2013. Compost bedded pack dairy barn management, performance, and producer satisfaction. Journal of Dairy Science. 96:8060–8074.

Blackhurst, M., C. Hendrickson, and H.S. Matthews. 2010. Cost-effectiveness of green roofs. Journal of Architectural Engineering. 16:136-143.

Bramley, A. J. 1982. Sources of Streptococcus uberis in the dairy herd: Isolation from bovine faces and from straw bedding of cattle. Journal of Dairy Research. 49:369-373.

Brenninkmeyer, C., S. Dippel, J. Brinkmann, S. March, C. Winckler, and U. Knierim. 2012. Hock lesion epidemiology in cubicle housed dairy cows across two breeds, farming systems and countries. Preventive Veterinary Medicine. 109:236–245.

Burow, E., P.R. Thomsen, T. Rousing, and J.T. Sørensen. 2012. Daily grazing time as a risk factor for alterations at the hock joint integument in dairy cows. Animal. 7:160–166.

Calcagno, V., and C. de Mazancourt. 2010. glmulti: an R package for easy automated model selection with (generalized) linear models. Journal of Statistical Software. 2010; 34:1-29.

Cameron, R.W.F., J.E. Taylor, and M.R. Emmett. 2014. What's ‘cool’ in the world of green façades? How plant choice influences the cooling properties of green walls. Building and Environment. 73:198-207.

CIGR. 1994. The design of dairy cow housing. Report of the CIGR Section II Working group No 14, Cattle housing. Farm buildings research team. ADAS Bridgets Dairy Research Centre, Winchester, Hampshire, UK.

Cook, N. B. 2003. Prevalence of lameness among dairy cattle in Wisconsin as a function of housing type and stall surface. Journal of the American Veterinary Medical Association. 223:1324-1328.

Cook, N. B., T. B. Bennett, and K. V. Nordlund. 2004. Effect of free stall surface on daily activity patterns in dairy cows with relevance to lameness prevalence. Journal of Dairy Science. 87:2912–2922.

de Boer, H. 2014. On farm development of bedded pack dairy barns in The Netherlands - Nutrient balances and manure quality of bedding material. Report 709. Wageningen UR Livestock Research, Lelystad, NL.

den Hollander, B. 2014. Samenstelling en werking van humest, in: Symposium Vrijloopstallen: State of the art uit onderzoek en pratijk. Bunschoten, The Netherlands, 13 February 2014.

Dippel, S., M. Dolezal, C. Brenninkmeyer, J. Brinkmann, S. March, U. Knierim, and C. Winckler. 2009. Risk factors for lameness in freestall-housed dairy cows across two breeds, farming systems, and countries. Journal of Dairy Science. 92:5476-5486.

Driehuis, F., E. Lucas-van den Bos, and M.H.J. Wells-Bennik. 2012. Risks of microbial contaminants of bedding materials: compost, cattle manure solids, horse dung and bedded pack barns. NIZO-report 2012/119. NIZO, Ede, NL.

Driehuis, F., E. Lucas-van den Bos, and M.H.J. Wells-Bennik. 2014. Spores of thermophilic aerobic sporeformers in compost and other bedding materials used by dairy farms with a bedded pack or freestall barn. NIZO-report 2014/045. NIZO, Ede, NL.

Dvorak, B., and A. Volder. 2010. Green roof vegetation for North American ecoregions: a literature review. Landscape and Urban Planning. 96:197–213.

Ecim-Djuric, O., and G. Topisirovic. 2010. Energy efficiency optimization of combined ventilation systems in livestock buildings. Energy and Buildings. 42:1165-1171.

EFSA. 2009. Scientific report of EFSA prepared by the Animal Health and Animal Welfare Unit on the effects of farming systems on dairy cow welfare and disease. Annex to the EFSA Journal. 1143:1-284.

Eicher, S.D., D.C. Lay, J.D. Arthington, and M.M. Schutz. 2013. Effects of rubber flooring during the first 2 lactations on production, locomotion, hoof health, immune functions, and stress. Journal of Dairy Science. 96:3639–3651.

Endres, M.I., and A.E. Barberg. 2007. Behavior of Dairy Cows in an Alternative Bedded-Pack Housing System. Journal of Dairy Science. 90:4192–4200.

Espejo, L. A., M. I. Endres, and J. A. Salfer. 2006. Prevalence of lameness in high-producing Holstein cows housed in freestall barns in Minnesota. Journal of Dairy Science. 89:3052-3058.

Farm Animal Welfare Council. 1997. Report on the welfare of dairy cattle. FAWC. Tolworth, United Kindom.

Fetrow, J., K. V. Nordlund, and H. D. Norman. 2006. Invited review: Culling: Nomenclature, definitions, and recommendations. Journal of Dairy Science. 89:1896–1905.

Fjeldaas, T., Å.M. Sogstad, and O. Østerås. 2011. Locomotion and claw disorders in Norwegian dairy cows housed in freestalls with slatted concrete, solid concrete, or solid rubber flooring in the alleys. Journal of Dairy Science. 94:1243–1255.

Francescato, V., E. Antonini, and L. Zuccoli Bergomi. 2009. Manuale pratico – Legna e Cippato – Produzione, requisisti normativi e compravendita. AIEL – Associazione Italiana Energie Agroforestali. Legnaro PD. Italy.

Frankena, K., J.G.C.J. Somers, W.G.P. Schouten, J.V. van Stek, J.H.M. Metz, E.N. Stassen, and E.A.M. Graat. 2009. The effect of digital lesions and floor type on locomotion score in Dutch dairy cows. Preventive Veterinary Medicine. 88:150-157.

Fregonesi, J.A., and J.D. Leaver. 2001. Behaviour, performance and health indicators of welfare for dairy cows housed in strawyard or cubicle systems. Livestock Production Science. 68:205–216.

Fregonesi, J.A., D.M. Veira, M.A.G. von Keyserlingk, and D.M. Weary. 2007. Effects of bedding quality on lying behavior of dairy cows. Journal of Dairy Science. 90:5468–5472.

Fregonesi, J.A., M.A.G. von Keyserlingk, C.B. Tucker, D.M. Veira, and D.M. Weary. 2009. Neck-rail position in the free stall affects standing behavior and udder and stall cleanliness. Journal of Dairy Science. 92:1979–1985.

Fulwider, W.K., T. Grandin, D.J. Garrick, T.E. Engle, W.D. Lamm, N.L. Dalsted, and B.E. Rollin. 2007. Influence of free-stall base on tarsal joint lesions and hygiene in dairy cows. Journal of Dairy Science. 90:3559–3566.

Galama, P. J., S. Bokma, H. J. van Dooren, W. Ouweltjes, M. Smits, and F. Driehuis. 2011. Prospects for bedded pack barns for dairy cattle. Wageningen UR Livestock Research, Lelystad, NL.

Galama, P.J. 2014. On farm development of bedded pack dairy barns in The Netherlands. Report 707. Wageningen UR Livestock Research, Lelystad, NL.

Galama, P.J., H. de Boer, H. J. van Dooren, W. Ouweltjes, J. Poelarends, S. Bokma and F. Driehuis. 2014. Vrijloopstallen voor melkvee in de praktijk. Wageningen UR Livestock Research, Lelystad, NL.

Gomez, A., and N.B. Cook. 2010. Time budgets of lactating dairy cattle in commercial freestall herds. Journal of Dairy Science. 93: 5772–5781.

Gooch, C. 2008. Dairy Freestall Barn Design – A Northeast Perspective. Ninth Annual Fall Dairy Conference. November 12 -13, 2008. Cornell University College of Veterinary Medicine and Cornell PRO-DAIRY Program.

Hadley, G. L., C. A. Wolf, and S. B. Harsh. 2006. Dairy cattle culling patterns, explanations, and implications. Journal of Dairy Science. 89:2286–2296.

Haley, D. B., A. M. de Passille´, and J. Rushen. 2001. Assessing cow comfort: Effects of two floor types and two tie stall designs on the behaviour of lactating dairy cows. Applied Animal Behavior Science. 71:105–117.

Haskell, M. J., L. J. Rennie, V. A. Bowell, M. J. Bell, and A. B. Lawrence. 2006. Housing system, milk production, and zero-grazing effects on lameness and leg injury in dairy cows. Journal of Dairy Science. 89:4259–4266.

Havermans, M. 2014. Zomer- en wintertips, in: Symposium Vrijloopstallen: State of the art uit onderzoek en pratijk. Bunschoten, The Netherlands, 13 February 2014.

Honig, H., J. Miron, H. Lehrer, S. Jackoby, M. Zachut, A. Zinou, Y. Portnick, and U. Moallem. 2012. Performance and welfare of high-yielding dairy cows subjected to 5 or 8 cooling sessions daily under hot and humid climate. Journal of Dairy Science. 95:3736–3742.

Hunter, A.M., N.S.G. Williams, J.P. Rayner, L. Aye, D. Hes, and S.J. Livesley. 2014. Quantifying the thermal performance of green façades: A critical review. Ecological Engineering. 63:102-113.

IPCC. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Ito, K., M.A.G. von Keyserlingk, S.J. LeBlanc, and D.M. Weary. 2010. Lying behavior as an indicator of lameness in dairy cows. Journal of Dairy Science. 93:3553–3560.

Jaffal, I., Ouldboukhitine S.E., and Belarbi R. 2012. A comprehensive study of the impact of green roofs on building energy performance. Renewable Energy. 43:157-164.

Janni, K. A., M. I. Endres, J. K. Reneau, and W. W. Schoper. 2007. Compost dairy barn layout and management recommendations. Applied Engineering in Agriculture. 23:97–102.

Jasper, D. E. 1980. The coliform mastitis enigma: Cows, sawdust, softwood shavings, bedding. Pages 23–34 in Proc. Int. Congr. Dis. Cattle, Tel-Aviv, Israel. Bregman Press, Haifa, Israel.

Jeppsson, K. H. 1999. Volatilization of ammonia in deep-litter systems with different bedding materials for young cattle. Journal of Agricultural Engineering Research. 73:49-57.

Jonckheere, I., S. Fleck, K. Nackaerts, B. Muys, P. Coppin, M. Weiss, and F. Baret. 2004. Review of methods for in situ leaf area index determination: Part I. Theories, sensors and hemispherical photography. Agricultural and Forest Meteorology. 121:19-35.

Jordan, E.R. 2003. Effects of Heat Stress on Reproduction. Journal of Dairy Science. 86:104–114.

Kester, E., M. Holzhauer, and K. Frankena. 2014. A descriptive review of the prevalence and risk factors of hock lesions in dairy cows. The Veterinary Journal. 202:222-228.

Kielland, C., L.E. Ruud, A.J. Zanella, and O. Osteras. 2009. Prevalence and risk factors for skin lesions on legs of dairy cattle housed in freestalls in Norway. Journal of Dairy Science 92, 5487–5496.

Klaas, I. C., and B. S. Bjerg. 2011. Compost barns - An alternative housing system for dairy cows? CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources. 6(045):1-9.

Klaas, I. C., B. S. Bjerg, S. Friedmann, and D. Bar. 2010. Cultivated barns for dairy cows: An option to promote cattle welfare and environmental protection in Denmark? Dansk Veterinærtidsskrift. 93:20–29.

Koyama, T., M. Yoshinaga, K. Maeda, and A. Yamauchi. 2014. Room temperature reductions in relation to growth traits of kudzu vine (Pueraria lobata): Experimental quantification. Ecological Engineering. 70:217-226.

Kumar, K.S., K.N. Tiwari, M.K. and Jha. 2009. Design and technology for greenhouse cooling in tropical and subtropical regions: A review. Energy and Buildings. 41:1269-1275.

Kumar, R., and S.C. Kaushik. 2005. Performance evaluation of green roof and shading for thermal protection of buildings. Building and Environment. 40:1505-1511.

Lamnatou, C., and D. Chemisana. 2013. Solar radiation manipulations and their role in greenhouse claddings: Fresnel lenses, NIR- and UV-blocking materials. Renewable and Sustainable Energy Reviews. 18:271-287.

Legrand, A., K.E. Schütz, and C.B. Tucker. 2011. Using water to cool cattle: Behavioral and physiological changes associated with voluntary use of cow showers. Journal of Dairy Science. 94:3376–3386.

Leonard, J. 2001. Composting, an alternative approach to manure management. Advances in Dairy Technology. 13:431-441.

Leso, L, M. Uberti, W. Morshed, and M. Barbari. 2013. A survey of Italian compost dairy barns. Journal of Agricultural Engineering. 44:120-124.

Lobeck, K. M., M. I. Endres, E. M. Shane, S. M. Godden, and J. Fetrow. 2011. Animal welfare in cross-ventilated, compost-bedded pack, and naturally ventilated dairy barns in the upper Midwest. Journal of Dairy Science. 94:5469–5479.

Lobeck, K. M., M. I. Endres, K. A. Janni, S. M. Godden, and J. Fetrow. 2012. Environmental characteristics and bacterial counts in bedding and milk bulk tank of low profile cross-ventilated, naturally ventilated, and compost bedded pack dairy barns. Applied Engineering in Agriculture. 28:117–128.

López-Gatius, F. 2012. Factors of a noninfectious nature affecting fertility after artificial insemination in lactating dairy cows. A review. Theriogenology. 77:1029-1041.

López-Gatius, F., P. Santolaria, I. Mundet, and J.L. Yániz. 2005. Walking activity at estrus and subsequent fertility in dairy cows. Theriogenology. 63:1419-1429.

Manske, T., J. Hultgren, and C. Bergsten. 2002. Prevalence and interrelationships of hoof lesions and lameness in Swedish dairy cows. Preventive Veterinary Medicine. 54:247-263.

Newman, L. E., and J. J. Kowalski. 1973. Fresh sawdust bedding-A possible source of *Klebsiella* organisms. American Journal of Veterinary Research. 34:979-980.

Norring, M., E. Manninen, A.M. de Passillé, J. Rushen, L. Munksgaard, and H. Saloniemi. 2008. Effects of sand and straw bedding on the lying behavior, cleanliness, and hoof and hock injuries of dairy cows. Journal of Dairy Science. 91:570–576.

NRAES (Northeast Regional Agricultural Engineering Service). 1992. On-Farm Composting Handbook. NRAES-54. NRAES, Ithaca, NY.

Ofner-Schröck, E., M. Zähner, G. Huber, K. Guldimann, T. Guggenberger, and J. Gasteiner. 2013. Kompoststall - Funktionell und tiergerecht? Bautagung Raumberg-Gumpenstein. 2013:15-22.

Ouweltjes, W., and G. Smolders. 2014. On farm development of bedded pack dairy barns in The Netherlands - Animal welfare and milk quality. Report 708. Wageningen UR Livestock Research, Lelystad, NL.

Peeler, E. J., M. J. Green, J. L. Fitzpatrick, K. L. Morgan, and L. E. Green. 2000. Risk factors associated with clinical mastitis in low somatic cell count British dairy herds. Journal of Dairy Science. 83:2464–2472.

Pérez, G., J. Coma, I. Martorell, and L.F. Cabeza. 2014. Vertical Greenery Systems (VGS) for energy saving in buildings: A review. Renewable and Sustainable Energy Reviews. 39:139-165.

Pinedo, P.J., A. Daniels, J. Shumaker, and A. De Vries. 2014. Dynamics of culling for Jersey, Holstein, and Jersey × Holstein crossbred cows in large multibreed dairy herds. Journal of Dairy Science. 97:2886–2895.

Platz, S., F. Ahrens, E. Bahrs, S. Nuske, and M. H. Erhard. 2007. Association between floor type and behaviour, skin lesions, and claw dimensions in group-housed fattening bulls. Preventive Veterinary Medicine. 80:209–221.

Platz, S., F. Ahrens, J. Bendel, H.H.D. Meyer, and M.H. Erhard. 2008. What happens with cow behavior when replacing concrete slatted floor by rubber coating: a case study. Journal of Dairy Science. 91:999–1004.

Progressive Dairy Operators. 2011. Report: Progressive Dairy Operators Study Tour to Israel. November 18 to 29, 2011. Available at: http://www.lho-ontario.ca/PDF/PDO%20Israel%20Trip%20Report%20-%20PDO.pdf

Quaiffe, T. 2002. Don't blame the big guys for higher heifer prices. Dairy Herd Management. January:26–28.

R Development Core Team. 2011. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available from: http://www.R-project.org/

R Development Core Team. 2011. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available from: http://www.R-project.org/.

Regione Emilia-Romagna. 2008. Prezzario regionale per opere e interventi in agricoltura – Adeguamento 2007. I supplementi di Agricoltura 36. Bologna (BO). Italy.

Rosen, C., T. R. Halback, and R. Mugaas. 2000. Composting and mulching: A guide to managing organic yard waste. University of Minnesota Extension Publication # BU-3296-GO. St. Paul, Minnesota: University of Minnesota.

Rynk, R., M. van de Kamp, G.B. Willson, M.E. Singley, T.L. Richard, J.J. Kolega, F.R. Gouin, L. Laliberty Jr., D. Kay, D.W. Murphy, H.A.J. Hoitink and W.F. Brinton. 1992. On-Farm composting handbook. (ed). R. Rynk. p. 6-13, 106-113. Northeast Regional Agricultural Engineering Service, Ithaca, NY.

Saadatian, O., K. Sopian, E. Salleh, C.H. Lim, S, Riffat, E, Saadatian, A, Toudeshki, and M.Y. Sulaiman. 2013. A review of energy aspects of green roofs. Renewable and Sustainable Energy Reviews. 23:155-168.

Schefers, J.M., K.A. Weigel, C.L. Rawson, N.R. Zwald, and N.B. Cook. 2010. Management practices associated with conception rate and service rate of lactating Holstein cows in large, commercial dairy herds. Journal of Dairy Science. 93:1459–1467.

Schirmann, K., N. Chapinal, D.M. Weary, W. Heuwieser, and M.A.G. von Keyserlingk. 2012. Rumination and its relationship to feeding and lying behavior in Holstein dairy cows. Journal of Dairy Science. 95:3212–3217.

Sethi, V.P., and S.K. Sharma. 2007. Survey of cooling technologies for worldwide agricultural greenhouse applications. Solar Energy. 81:1447-1459.

Shane, E. M., M. I. Endres, D. G. Johnson, and J. K. Reneau. 2010. Bedding options for an alternative housing system for dairy cows: A descriptive study. Applied Engineering in Agriculture. 26:659-666.

Smits, M.C.J., and A.J.A. Aarnink. 2009. Verdamping uit ligbodems van vrijloopstallen; oriënterende modelberekeningen. Report 230. Wageningen UR Livestock Research, Lelystad, NL.

Somers, J.G.C.J., K. Frankena, E.N. Noordhuizen-Stassen, and J.H.M. Metz. 2003. prevalence of claw disorders in Dutch dairy cows exposed to several floor systems. Journal of Dairy Science. 86:2082–2093.

Somers, J.G.C.J., W.G.P. Schouten, K. Frankena, E.N. Noordhuizen-Stassen, and J.H.M. Metz. 2005. Development of claw traits and claw lesions in dairy cows kept on different floor systems. Journal of Dairy Science. 88:110–120.

Sprecher, Y. 2013. Cultivated bedding in loose housing sheds (Bedded Pack Barns). Sprecher Architects report. Tel-Aviv. Israel.

Stentiford, E. I. 1996. Composting control: principles and practice. in the science of composting, Part 1. M. de Bertoldi, P. Sequi, B. Lemmes, and T. Papi, ed. Blackie Academic and Professional, London, UK.

Tao, S., and G.E. Dahl. 2013. Invited review: Heat stress effects during late gestation on dry cows and their calves. Journal of Dairy Science. 96:4079-4093.

Telezhenko, E., and C. Bergsten. 2005. Influence of floor type on the locomotion of dairy cows. Applied Animal Behaviour Science. 93:183-197.

Telezhenko, E., C. Bergsten, M. Magnusson, and C. Nilsson. 2009. Effect of different flooring systems on claw conformation of dairy cows. Journal of Dairy Science. 92:2625–2633.

Tucker C.B., D.M. Weary, and D. Fraser. 2005. Influence of neck-rail placement on free-stall preference, use, and cleanliness. Journal of Dairy Science. 88:2730–2737.

van Dooren, H.J.C., P.J. Galama, M.C.J. Smits, W. Ouweltjes, F. Driehuis, and S. Bokma. 2011. Bodems voor vrijloopstallen. Report 411. Wageningen UR Livestock Research, Lelystad, NL.

Vanegas, J., M. Overton, S.L. Berry, and W.M. Sischo. 2006. Effect of rubber flooring on claw health in lactating dairy cows housed in free-stall barns. Journal of Dairy Science. 89:4251–4258.

Vanthoor, B.H.E., C. Stanghellini, E.J. van Henten, and P.H.B. de Visse. 2011. A methodology for model-based greenhouse design: Part 1, a greenhouse climate model for a broad range of designs and climates. Biosystems Engineering. 110:363-377.

Veissier, I., J. Capdeville, and E. Delval. 2004. Cubicle housing systems for cattle: Comfort of dairy cows depends on cubicle adjustment. Journal of Animal Science. 82:3321–3337.

Ventura, P.G. 2011. Un modello innovativo per le stalle europee. Stalle da latte. 29:30-2.

Vighi, P., M. Uberti, and L. Calamari. 2009. Più benessere per le bovine con l’erpicatura della lettiera. Terra e Vita 24:43-6.

Vitali, A., M. Segnalini, L. Bertocchi, U. Bernabucci, A. Nardone, and N. Lacetera. 2009. Seasonal pattern of mortality and relationships between mortality and temperature-humidity index in dairy cows. Journal of Dairy Science. 92:3781–3790.

von Keyserlingk, M.A.G., A. Barrientos, K. Ito, E. Galo, D.M. Weary. 2012. Benchmarking cow comfort on North American freestall dairies: Lameness, leg injuries, lying time, facility design, and management for high-producing Holstein dairy cows. Journal of Dairy Science. 95:7399–7408.

von Keyserlingk, M.A.G., J. Rushen, A.M. de Passillé, and D.M. Weary. 2009. Invited review: The welfare of dairy cattle - Key concepts and the role of science. Journal of Dairy Science. 92 :4101–4111.

Wagner, P. E. 2002. Bedded pack shelters. Available at http://crbh.psu.edu/das/research-extension/dairy/dairy-digest/articles/bedded-pack-shelters.

Weary, D.M., and I. Taszkun. 2000. Hock lesions and free-stall design. Journal of Dairy Science. 83:697–702.

Webster, J. 1995. Animal welfare: a cool eye towards Eden: a constructive approach to the problem of man's domination over animals. Blackwell Science, Oxford, UK.

Weigel, K. A., R. W. Palmer, and D. Z. Caraviello. 2003. Investigation of factors affecting voluntary and involuntary culling in expanding dairy herds in Wisconsin using survival analysis. Journal of Dairy Science. 86:1482–1486.

Welfare Quality®. 2009. Welfare Quality® assessment protocol for cattle. Welfare Quality® Consortium, Lelystad, Netherlands.

West, J.W. 2003. Effects of Heat-Stress on Production in Dairy Cattle. Journal of Dairy Science. 86:2131-2144.

Worley, J. W., and J. K. Bernard. 2008. Cooling Effectiveness of High-Volume Low-Speed Fans Versus Conventional Fans in a Free-Stall Dairy Barn in Hot, Humid Conditions. The Professional Animal Scientist 24:23–28.