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Loose Housing of Horses in a Cold Climate

Effects on Behaviour, Nutrition, Growth and Cold Resistance

Doctoral dissertation

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ABSTRACT

Housing of weanling horses in cold loose housing systems is common in the Nordic countries, although its suitability as a winter environment has not been studied. This thesis aimed to study the effects of a cold loose housing environment on weanling horses. The loose housing system consisted of insulated halls with a deep-litter bed, entrance shelters and paddocks to which the group-housed horses had free access. The effects on the behaviour, nutrition, growth and cold resistance of the horses were studied.

The time budget of the horses consisted mainly of eating, resting and standing (37, 32, and 26 % of daily time, respectively); only one hour (5 %) was spent on locomotor activity. Their circadian rhythm largely resembled that of feral horses. The horses acclimatized to the cold by behavioural, metabolic and insulation adjustments. Their activity was low and huddling existed commonly. Energy intake increased by 1.8, 0.5 and 0.2 % in November, December and January, respectively, per 1 °C decrease in ambient temperature below the lower critical temperature of –11 ºC. When this demand was taken into account in the feeding, the horses gained weight at expected rates. The results for radiative heat loss and winter coat development indicated that differences existed in the cold resistance of the horses, coldblood and pony types being more resistant than light and warmblood types.

A loose housing system contributes to horse welfare by allowing horses to follow the natural circadian rhythm of behavioural patterns, but does not necessarily encourage activity. The opportunity to behave unrestrictedly rather than the opportunity for high locomotor activity seems to be more important for horses. Weanling horses cope in the cold and thus can be reared in loose housing systems provided their level of acclimatization is taken into account in the feeding and that the loose housing facilities are adequate. However, due to changing animal- and environment-related factors during the winter and ad libitum forage feeding, the regulation of nutrient intake is complicated and the risk of overfeeding and imbalanced nutrition is high in late winter.

With regard to horse welfare, this thesis indicates that loose housing may involve both advantages and disadvantages. The suitability of loose housing for weanling horses depends on which welfare-related features are emphasized.
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ABBREVIATIONS

ADG  Average daily gain
BAT  Brown adipose tissue
BCS  Body condition score
BMR  Basal metabolic rate
BW   Body weight
C    Coldblood horse type
CED  Climatic energy demand
DM   Dry matter
FC   Finnish coldblood horse, i.e. Finnhorse
GPS  Global Positioning System
HI   Heat increment
HP   Heat production
HR   Heart rate
L    Light horse type
LCT  Lower critical temperature
LMM  Linear Mixed Model
ME   Metabolizable energy
MR   Metabolic rate
NST  Non-shivering thermogenesis
P    Pony type
QH   Quarter Horse
RH   Relative humidity
RQ   Respiratory quotient
SB   Standardbred horse
T_a  Ambient temperature
T_b  Body temperature
TB   Thoroughbred horse
TNZ  Thermoneutral zone
W    Warmblood horse type

DEFINITIONS

Foal   A young horse from the time of birth until weaning (Belknap, 1997)
Weanling A foal separated from its dam until the first birthday (Belknap, 1997)
Yearling A foal between one and two years of age (Belknap, 1997)
LIST OF ORIGINAL PUBLICATIONS

This dissertation is based on the following original publications, which are referred in the text by their Roman numerals I–IV:


This thesis also contains previously unpublished data referred to in the text as U₁ and U₂.
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APPENDIX: ORIGINAL PUBLICATIONS
1. INTRODUCTION

A great proportion of the world’s horse population is located in cold climate countries or at least in countries with a cold winter (Langlois, 1994). The most common way of housing horses in these regions during the long indoor feeding period is confinement in stables in loose boxes (Mills & Clarke, 2002). However, stabling limits the amount of free exercise horses can take and their social contacts, and reduces environmental stimulation (Fader & Sambraus, 2004). Therefore, an alternative housing system, loose housing, has been established to solve the problems caused by stabling. A loose house is a group housing system where horses have free access to an unheated hall with bedding and a paddock (Ventorp, 1994). Free outdoor access is expected to encourage voluntary daily exercise of horses, which is limited in box stabling (Zeeb & Schnitzer, 1997).

In Finland, the number of registered horses is about 68,000 (Suomen Hippos, 2008). This number, and especially the proportion of horses raised for hobby and leisure purposes, is continuously increasing. Horse breeding is mainly carried on by small breeders, since over 80% of Finnish breeders have only one or two broodmares (Heiskanen et al., 2002). Nowadays, it is common for small breeders to rear weaned foals during their first winter in a commercial group housing system, i.e. a loose housing system, in which foals are collected from several different stables in autumn. In Finland, the number of loose housing systems with five to ten horses is estimated to be about 200 (executive directors of the regional horse breeding associations, personal communication, October 2, 2007). In addition, there is a large, undefined number of loose houses with one to four horses.

Loose housing of horses in regions with a long and cold winter, such as Finland, exposes the horses to considerable weather fluctuations and low ambient temperatures. Scientific knowledge on the effects of the cold, especially on growing horses during prolonged exposure to cold, is limited. Recently, feedback from Finnish veterinarians and the executive directors of the regional horse breeding associations revealed that a lack of knowledge and skills in taking care of horses in a cold environment has caused health and welfare problems, especially in young, loose-housed horses. The concern about the impacts of winter conditions on horse welfare has initiated discussion about the suitability and acceptability of loose housing of horses in a cold, northern climate. Since loose housing provides a useful alternative to stabling with several benefits, e.g. the opportunity for free exercise and social contacts, this housing method should be studied and developed further to enhance the health and welfare of loose-housed horses.

In the late 1990s, the Ylä-Savo Federation of Municipalities for Education founded a development project “Equine Information Centre” in Eastern Finland to advance the Finnish horse industry and current horse management practices. The Equine Information Centre designed a research loose housing system on the school farm of the Ylä-Savo Vocational Institute in Kuuruvesi, where an extensive research project was conducted in 2002–2006 into the effects of a cold housing environment on horses. The present study, which is based on this research project, aimed to determine the suitability of a loose housing system as a winter environment for weanling horses.
2. REVIEW OF THE LITERATURE

2.1 Horse housing alternatives in relation to health and welfare

The horse is a herding, free-ranging herbivore, which spends most of the day foraging (McGreevy, 2004). The herd, which is characterized by a strong social hierarchy, provides safety and social comfort for the horse. As a prey animal, the self-preservation of the horse relies mainly on an open environment that enables early detection and fast escape from predators. The possibility to seek shelter and relief from adverse weather conditions, such as storms, wind, cold, heat and sun, is important for the horse (McDonnell, 2003). The herd also contributes to the heat balance of the horse by providing shelter from the adverse effects of weather (Morgan, 1996; Ingólfsdóttir & Sigurjónsdóttir, 2008).

Current horse housing environments differ to a great extent from the horse’s natural habitat and social environment. In order to ensure the health and welfare of domestic horses, the horse’s natural characteristics should be taken into account in horse management. In addition to behavioural characteristics, also nutritional needs, cold resistance, type of use, individual features (e.g. health and temperament) as well as general and regional climatic conditions should be considered when selecting a winter housing system for the horse. Since the selection of a housing system, which contributes to horse welfare, is a multidimensional question, alternatives should be considered from different standpoints.

Horses can be generally classified into three groups according to the type of use: growing horses, mature horses used for various purposes, e.g. recreation, sport or competition, and breeding horses. These groups have unique demands in terms of housing and care. In growing horses, one of the most important things is to ensure the normal growth and development of the musculoskeletal system. In particular, adequate exercise (Raub et al., 1989; Bell et al., 2001; van de Lest et al., 2002; Rogers et al., 2008; van Weeren et al., 2008) and balanced nutrition (Glade & Belling, 1984; Glade et al., 1984; Cymbaluk et al., 1989a, 1989b, 1990) are essential. The company of age-mates is important since it may improve the sociability (Christensen et al., 2002) and manageability (Søndergaard & Ladewig, 2004) of growing horses.

The most common housing alternatives for the indoor feeding period are stabling in single, loose boxes and loose housing in groups (Zeep & Schnitzer, 1997). In addition, tethering in stalls is used to some extent in Europe, but, for example, according to the Finnish Ministry of Agriculture and Forestry decree on animal welfare requirements for horses (14/EEO/1998), tethering should nowadays be avoided. None of these housing options is ideal, with each system having advantages and disadvantages and thus posing different risks to horse welfare (Clarke, 1994; Mills & Clarke, 2002). In the following, the features of the most common housing systems in relation to horse health and welfare are discussed.

2.1.1 Stabling in loose boxes

Stabling in loose boxes with restricted turnout in paddocks has several advantages (Mills & Clarke, 2002). Stabling protects the horse from adverse weather conditions (McGreevy, 2004), and allows each horse to have personal space and a management routine (Mills & Clarke, 2002). The horse’s feed quality and intake, and the amount of exercise can be controlled, and the risk of injuries is low. The manageability of stabled young horses has also been reported to
be better than that of horses in more natural environments due to daily handling (Jezierski et al., 1999).

Stabling has several disadvantages related especially to horses’ behavioural needs (Mills & Clarke, 2002). Stabled horses may have rather different time budgets than horses in more natural environments depending on feeding practices (Kiley-Worthington, 1987), and also different circadian rhythms of behaviour, e.g. sleep patterns (Dallaire, 1986). The most remarkable differences in time budgets are in the time spent eating and standing (Table 1). Stabled horses spend much more standing and less time eating than free-ranging horses due to the limited opportunity for exercise and foraging, which may cause frustration and affect the gastrointestinal function (McGreevy, 2004). Stabled horses also lack an opportunity to interact with other horses (Rivera et al., 2002), which may, for example, increase aggression towards other horses (McGreevy, 2004). Chronic frustration and distress, and management and feeding practices associated with stabling may further lead to psychological reactions (Mills & Clarke, 2002) in the form of aberrant or unwanted (Heleski et al., 2002; Rivera et al., 2002), aggressive (Christensen et al., 2002; Søndergaard & Ladewig, 2004) and stereotypic behaviour, such as weaving, crib-biting, wind-sucking and box-walking (McGreevy et al., 1995; Normando et al., 2002; Waters et al., 2002; Ninomiya et al., 2007; Parker et al., 2008).

The major physical health concern is respiratory health (Mills & Clarke, 2002). Stabling may predispose the horse to high levels of ammonia, organic dusts and mould spores originating from bedding materials and forages, especially when the ventilation in the stable is poor (Tuomivaara, 1992; Clarke, 1994; Airaksinen, 2006; Hotchkiss et al., 2007). Therefore, stabling has been associated with airway inflammations (Tremblay et al., 1993; Holcombe et al., 2001). In addition, stabling without the opportunity for exercise may retard the musculoskeletal development of growing horses (Raub et al., 1989; Bell et al., 2001; van de Lest et al., 2002; Hiney et al., 2004).

These facts suggest that stabling may cause horses both psychological and physical stress (Mills & Clarke, 2002). However, the negative impacts of stabling could be greatly minimized by management changes, e.g. by avoiding dusty bedding materials and poor-quality forages, and by adequate ventilation (Mills & Clarke, 2002; Hotchkiss et al., 2007).

### 2.1.2 Loose housing

A loose house is typically a group housing system where horses have free access to an unheated sleeping hall with bedding and an outdoor paddock (Ventorp, 1994). Loose housing became common in many parts of Europe, e.g. in Germany (Fader & Sambraus, 2004) and Sweden (Ventorp, 1994) in the early 1990s, and in Finland in the late

| Table 1. Examples of the time budgets of free-ranging and stabled horses (Kiley-Worthington, 1987). |
|-----------------|-----------------|-----------------|-----------------|
| **Behaviour (%)** | **Free-ranging horses** | **Stabled horses, fed ad libitum** | **Stabled horses, controlled feeding** |
| Eat | 60 | 47 | 15 |
| Stand | 20 | 40 | 65 |
| Lie | 10 | 10 | 15 |
| Other | 10 | 3 | 5 |
1990s. A loose house is considered a more appropriate housing system for horses than a box stable because it is expected to provide a better opportunity to satisfy behavioural needs (Bender, 1992; Zeeb & Schnitzer, 1997). The time budgets of outdoor-housed horses may thus resemble time budgets of feral horses (Heleski et al., 2002). Furthermore, horses have the opportunity to exercise freely, which should encourage daily locomotor activity (Zeeb & Schnitzer, 1997). Since adequate, regular exercise enhances the development of musculoskeletal system (Raub et al., 1989; Bell et al., 2001; van de Lest et al., 2002, 2003; Hiney et al., 2004), loose housing is expected to yield more healthy, athletic horses that are not as prone to strain injuries as stabled horses (Bender, 1992). The lower investment costs as well as the relatively low maintenance costs are also generally considered to be an advantage (Ventorp, 1994) since in Finland, for example, the space requirement per horse is smaller in a loose housing system than in a box stable (Ministry of Agriculture and Forestry, 1998). Space requirement in a loose housing system is 80% of the area for a loose box for mature horses, 60% for yearling horses and 40% for weanling horses.

However, loose housing may also have several shortcomings. For example, a high rate of voluntary exercise in the loose housing system cannot be regarded as self-evident. When paddocks are too small, horses do not exercise enough in order to ensure normal musculoskeletal development (Hiney et al., 2004) and aggressive behaviour towards other horses may increase (Hogan et al., 1988). In addition, the consequences of group housing may be different for horses located differently in the social ranking order, because low-ranking horses may not, for example, be able to rest adequately or at all in a lying position (Fader & Sambraus, 2004) and may have limited access to food and shelter (Ingólfsdóttir & Sigurjónsdóttir, 2008) due to interference by higher ranking horses. Moreover, the risk of injuries caused by kicking and biting may be substantial (Fürst et al., 2006). Situations such as establishment of the ranking order within the group hierarchy, agitation among the horses, and introduction of a new horse into an established group may provoke kicking and biting. Since horses have a strong social hierarchy (McGreevy, 2004), the smaller space requirements in a loose housing system compared to a box stable may not therefore be adequate and more space per horse may be required, thus diminishing the advantage in the investment costs.

Group housing may also affect horses’ reactions towards humans, since group-housed horses have been observed to seek contact with humans later and to be more difficult to approach than singly-housed horses (Søndergaard & Halekoh, 2003). Therefore, group housing may impair the human-animal relationship if the horses are not adequately handled (Søndergaard & Halekoh, 2003), although it should be noted that contradictory results also exist (Christensen et al., 2002; Søndergaard & Ladewig, 2004).

Outdoor-housed horses are also exposed to fluctuating weather conditions, such as variations in ambient temperature ($T_a$), precipitation, relative humidity (RH) and wind speed. The cold housing environment increases energy requirements of horses (Cymbaluk & Christison, 1989a; Cymbaluk, 1990), and hence also feed intake and feeding costs, but may also indirectly affect the health of the animals (Clark & McArthur, 1994). In a recent study, being outside in cold winter weather increased the risk of airway inflammations in horses (Robinson et al., 2006). The longer the horses were kept outdoors in a day, the greater was the risk of airway inflammation. It was specu-
ulated that cooling and drying of the airway mucosa in the cold may be responsible for inflammations. Cold-induced deaths have been reported in only a few cases. Deaths have occurred in horses living under close-to-natural conditions, and have been caused by severe nutritional and environmental stress (Dieterich & Holleman, 1973; van Dierendonck et al., 1996). Generally, the magnitude of the thermal challenge of the environment depends on how the horse can maintain its thermal balance with the aid of its thermal properties and its physiological regulatory mechanism in relation to the physical environment (Morgan et al., 1997).

2.2 General aspects of thermoregulation in the cold

2.2.1 Types of thermal responses

Thermal responses comprise all those adjustments of an organism’s anatomy, physiology and behaviour that reduce the physiological strain caused by the stressful components of the total environment (Clarke, 1991; IUPS Thermal Commission, 2003). The animal reacts to an immediate change in the environment by acute, instant responses (Young, 1975; Clarke, 1991 in Clarke, 1991), e.g. by activating mechanisms to regulate heat loss by vasoconstriction, piloerection and behaviour, and heat production (HP) by feed intake and shivering (Young, 1975). The acute responses depend on the animal’s acclimatization (i.e. phenotypic adaptation), which comprises the adjustments at the individual level within the lifetime of the animal in the natural climate (IUPS Thermal Commission, 2003), e.g. hormonal, metabolic and morphological adjustments (Young, 1975). Ultimately, genotypic adaptation, which encompasses the adjustments at the species level and is a result of natural selection, determines the type and magnitude of thermal responses by which an individual of a certain species is able to react (Davenport, 1992). Adaptive changes may appear in behaviour, insulation, metabolism and morphology (Young, 1975). Cold adaptation is hence a deep-seated adaptation in the species (Langlois, 1994).

2.2.2 Body temperature

Homeothermic endotherms, such as the horse, maintain body temperature (\(T_b\)) within a narrow range despite fluctuations in \(T_s\) (Young & Coote, 1973; Cross et al., 1991; Mogg & Pollitt, 1992; Ousey et al., 1992). Endotherms have significant internal sources of heat from metabolic processes, and have anatomical, physiological and behavioural mechanisms to control the heat loss so that a relatively constant \(T_b\) is maintained (Bicego et al., 2007). In mature horses, the normal core \(T_b\) is about 38.0 °C (Hines, 2004). Neonatal, rapidly growing, pregnant and lactating animals have a higher \(T_b\) (Sjaastad et al., 2003; Hines, 2004). It is considered that a deviation from normothermia of more than 1 °C leads to discomfort, and that a decrease of more than 10 °C or an increase by more than 5 °C is fatal (Langlois, 1994).

\(T_b\) is not constant throughout the body (Bligh, 1998). The body core has nearly constant temperature, but the temperature of the outer shell (i.e. skin and subcutaneous adipose tissue) varies considerably depending on the body site and \(T_s\). Generally, surface temperatures are lower on body areas with poor vascular supply, with bone underneath the skin and at the limbs (Young & Coote, 1973; Palmer, 1983; Mogg & Pollitt, 1992; Verschooten et al., 1997). The fluctuation in surface temperature in direct proportion to \(T_s\) is a thermoregulatory mechanism regulated by vasoconstriction or vasodilatation of cutaneous blood vessels (Palmer, 1983; Mogg & Pollitt, 1992).

\(T_b\) is regulated by nervous feedback mechanisms, which operate mostly through
temperature-regulating centres located in the hypothalamus (Bicego et al., 2007). The preoptic-anterior hypothalamus, skin and deep tissues, e.g. spinal chord, brain stem and the great veins, contain large numbers of temperature-sensitive neurons that monitor \( T_b \) (Boulant, 2000). The anterior hypothalamus contains large numbers of heat-sensitive neurons (Davenport, 1992; Hines, 2004), whereas peripheral receptors in the skin are most sensitive to cool and cold temperatures (Bicego et al., 2007). The preoptic region in the hypothalamus acts as coordinating centre that compares and integrates information from the central and peripheral neurons (Boulant, 2000).

A defended body temperature is the \( T_b \) that the body attempts to maintain (Bligh, 2006). It is thought to arise from the reciprocal crossing inhibition between the cold-sensitive and warm-sensitive neurons in the central nervous system. Therefore, a balance between the signals from cold-sensitive and warm-sensitive neurons determines the thermoregulatory set-level at which \( T_b \) is regulated by acute physiological responses, i.e. through heat-production or heat-loss effector pathways. Hence, the temperature difference between the body core and the skin is important in \( T_b \) regulation (Morgan, 1996).

### 2.2.3 Heat balance

The total heat content of the body determines \( T_b \) (Clark & McArthur, 1994). Heat is continuously generated as a by-product of metabolism, and thus \( T_b \) depends on the metabolic rate (MR) (Bicego et al., 2007). This metabolic heat is transferred from the deeper tissues to the skin, where it is lost to the air and other surroundings in a controlled manner (Morgan, 1997b). \( T_b \) remains constant when total heat loss, comprising non-evaporative (radiation, convection and conduction) and evaporative heat loss, equals heat gain, and changes in \( T_b \) are caused by alterations in this ratio (Clark & McArthur, 1994). The following equation (IUPS Thermal Commission, 2003) describes the body heat balance for a standing animal:

\[
\text{Storage of body heat} = \text{MR} \pm \text{evaporation} \pm \text{convection} \pm \text{conduction} \pm \text{radiation}
\]

When \( T_b \) decreases, the hypothalamus is activated and induces mechanisms which reduce heat loss and increase HP (Boulant, 2000). Heat loss-reducing mechanisms strive to increase body insulation and reduce the exposed surface area, while heat-producing mechanisms aim at increasing the metabolic HP. When the mechanisms are not sufficient to maintain heat balance, core \( T_b \) will fall below the normal level (hypothermia) (IUPS Thermal Commission, 2003).

Allometry, the systematic change in body proportions with increasing body size, has a great effect on heat balance both between and within animal species (Reiss, 1991). Changes within species occur as animals grow and develop but exist also between breeds of species (Reiss, 1991), e.g. in horses (Langlois, 1994). Generally, large body size is an advantage with respect to thermoregulation in the cold, since the ratio of heat-dissipating surface area to heat-producing/retaining body mass decreases with increasing body size (Phillips & Heath, 1995; Bligh, 1998). Therefore, large animals have less relative surface area available for heat exchange and experience proportionately less heat loss in the cold than small animals. Body size also affects the animal’s MR, which is approximately proportional to body mass by the exponent 0.75 (Bligh, 1998; Cannon & Nedergaard, 2004). Therefore, the mass-specific MR declines as body mass increases. Small animals usually depend on an ability to change the MR to regulate \( T_b \), whereas
large animals rely on adjustment of surface temperature to regulate heat exchange (Phillips & Heath, 1995; Lovegrove, 2005). In addition to large body size, a spherical body shape reduces the surface area to body mass ratio (Langlois, 1994). According to Allen’s rule, the relative size of exposed portions of the body decreases as $T_a$ decreases (Davenport, 1992). Accordingly, it is considered that northern types of a given mammalian species have smaller/shorter limbs, tails, ears and/or wings than southern types (Langlois, 1994).

### 2.2.4 Heat production

Heat is mainly produced as a by-product of catabolism – the breakdown of biochemical substrates (carbohydrates, fatty acids and proteins), but there is an inevitable production of heat from all metabolic processes, i.e. also from anabolic processes (Davenport, 1992). MR describes the total conversion of chemical energy into mechanical work and heat per unit time (IUPS Thermal Commission, 2003). The main ways of generating heat are the basal metabolic rate (BMR), shivering thermogenesis and cold-exposure induced non-shivering thermogenesis (NST) (Cannon & Nedergaard, 2004) and physical work, i.e. heat produced in the muscles during exercise (Hodgson et al., 1994). The BMR is the stable rate of energy metabolism measured under conditions of minimum environmental and physiological stress, i.e. in a rested, awake, fasting animal in a thermoneutral zone (TNZ) (IUPS Thermal Commission, 2003). The BMR represents the energy expenditure needed to maintain cell and organ functions (Bligh, 1998). At rest, about 60 % of the body’s HP occurs in the heart, liver, kidneys and brain (Sjaastad et al., 2003). The remaining 40 % is formed in the muscles, skin and skeleton.

The hypothalamus regulates the secretion of thyroid-stimulating hormone (TSH) from the pituitary gland, which further regulates the secretion of thyroid hormones, thyroxine and triiodothyronine, from the thyroid gland (Storer et al., 1979). Thyroid hormones raise the cellular metabolism in most body tissues, and thus the BMR is related to thyroid activity (Irvine, 1967). However, an increase in the BMR does not occur instantly after, say, acute cold exposure since the thyroid gland must increase in size before reaching a higher level of thyroid hormone secretion. Therefore, increased HP by means of thyroid hormones requires prolonged cold exposure (Sjaastad et al., 2003).

During moderate and maximal activity, HP increases greatly (Hodgson et al., 1994). Most of the body’s HP occurs in the muscles, since 80 % of the energy used during exercise is given off as heat. For example, in exercising horses, the heat generated was about 2,300 kcal at an exercise intensity of 40 % (38 min) of maximum $O_2$ uptake, and about 4,200 kcal at an exercise intensity of 90 % (9 min) (Hodgson et al., 1993), the power in the latter case being about eight times that in the former. About 7 to 20 % of the heat generated remained as stored heat post-exercise, which consequently increased the $T_h$ of the horses. But even minimal muscular activity may increase HP. For example, slight body movements increased the MR of a sleeping foal by about 18 % compared to inactive sleeping (Ousey et al., 1997).

In shivering thermogenesis, heat is rapidly produced by breaking down ATP in the muscles (Langlois, 1994). Shivering consists mainly of involuntary, contractile activity of skeletal muscles (IUPS Thermal Commission, 2003). As shivering progresses, its intensity may increase from muscle tone to microvibrations and even to visible contractions of both flexor and extensor muscles. Shivering is facilitated by the posterior area of hypothalamus and
suppressed by the preoptic area (Tanaka et al., 2001). Thus, the appearance of shivering depends on the balance between the signals from these two hypothalamic regions. Shivering is usually an acute response to a sudden cold exposure, but may be maintained even several months provided that the animal is able to develop the physical capacity (lung, heart and muscle capacity) necessary for a sustained shivering thermogenesis (Cannon & Nedergaard, 2004). Shivering may increase HP about fourfold as compared to the BMR. On the other hand, body movements associated with shivering may lower the thermal resistance of the body and increase heat loss (McArthur, 1991).

In NST, the MR increases during cold exposure without increased muscle activity (IUPS Thermal Commission, 2003). NST is under the control of norepinephrine released from sympathetic nerves (Cannon & Nedergaard, 2004). The principle effector organ is brown adipose tissue (BAT), where most of the energy released as a result of oxidation of glucose and lipids is not utilized to synthesize ATP as in most body tissues, but is instead dissipated entirely as heat. The capacity for HP by NST increases adaptively in the course of acclimatization to cold (IUPS Thermal Commission, 2003), and replaces shivering in the long term (Cannon & Nedergaard, 2004). BAT exists in mammalian species of smaller body size, e.g. rodents (Klaus et al., 1988; Trayhurn & Jennings, 1988; Haim et al., 1993; Saarela & Hissa, 1993), but is also present in newborns of larger species, e.g. calves (Alexander et al., 1975; Vermorel et al., 1983) and reindeers (Markussen et al., 1985; Soppela et al., 1991, 1992).

### 2.2.5 Heat loss
Heat transfer between an animal and its environment depends on the temperature gradient between the body core and the surroundings, and the surface area through which transfer takes place (Duncan, 1990). Heat transfer occurs by two main routes: non-evaporative heat loss (dry heat loss) by convection, conduction and thermal radiation, and evaporative heat loss (Clark & McArthur, 1994). Heat exchange can be regulated by several mechanisms: changes in circulation, hair coat, exposed surface area, respiration rate and sweating rate (McArthur, 1991; Morgan et al., 1997). In particular, body insulation, which causes the surface temperature to fall near to the level of $T_s$, efficiently reduces heat loss (Langlois, 1994).

The total body insulation consists of the body tissue, hair coat and air acting in series (McArthur, 1991). Thermal insulation of tissue acts between the body core and skin surface and depends on the thickness of the skin, on the amount of subcutaneous fat and on peripheral blood flow (Ousey et al., 1992). Tissue thermal insulation is regulated by vasomotor control of the blood flow to the periphery (Morgan, 1997a). The amount of fat is also important, since fat is three times more insulating than other tissues (Guyton, 1991). Coat insulation depends on the depth and thickness of the hair layer, the wind speed and the temperature and humidity gradients within the coat (Ousey et al., 1992). The coat insulation is controlled by bristling of the hair with the aid of hair erector muscles (Kainer et al., 1994; Morgan, 1997a). This piloerection, which is an autonomic response to cold, increases the thickness of the insulating, stationary air layer between hairs (Bligh, 1998).

Heat loss by convection occurs between an organism and its external environment in a moving gas or fluid, and depends on the temperature gradient (IUPS Thermal Commission, 2003). When the body surface temperature is higher than $T_s$, air in contact with the skin will be heated by conduction
and forms a stationary layer a few millimetres thick (Duncan, 1990). Outside this layer, warm air is moved away from the body by convective currents and replaced by cooler air. This natural convection accelerates as the $T_a$ decreases (McArthur, 1991). However, in animals with a hair coat, natural convection is of limited significance for heat loss, whereas convection due to wind or body movements, i.e. forced convection, is of greater importance (Davenport, 1992). Convection also occurs to some extent from the respiratory tract because the exhaled air is usually warmer than the inhaled air (Clark & McArthur, 1994; Morgan, 1997b). It has been estimated that convection by this route is about 3% of the total heat loss in housed stock (Clark & McArthur, 1994).

Conduction encompasses heat transfer between objects in contact with each other and may occur to solid material, gas or fluid between an organism and its external environment (IUPS Thermal Commission, 2003). In a cold environment, heat conduction to the air can be considerable since conduction follows the temperature gradient. However, when the temperature of the air layer immediately adjacent to the skin equals the temperature of the skin, no further heat conduction occurs (Guyton, 1991). In addition to the temperature gradient, heat conduction depends on the surface area of contact and the thermal properties of the object (Langlois, 1994). In a standing animal, only small quantities of heat are lost by conduction to objects, but when the animal is lying, heat conduction can be remarkable (Clark & McArthur, 1994). A wet body surface or lying surface increases conduction since the thermal conductivity of water is high.

In thermal radiation, heat transfer occurs in the form of electromagnetic waves in the infrared part of the spectrum (Danielsson et al., 1998). Also heat loss by radiation follows the heat gradient, i.e. when the animal’s body is warmer than the environment it loses heat by radiation (Langlois, 1994). It has been estimated that in large animals exposed to slowly moving air, about 50% of the non-evaporative heat loss will occur by radiation (Clark & McArthur, 1994). Radiative cooling may be high especially at night during the cold winter months (Cymbaluk & Christison, 1989a; Clark & McArthur, 1994). When $T_a$ is higher than the skin, the net transfer of heat by radiation is towards the animal, which may increase $T_e$ (Clark & McArthur, 1994). Animals can reduce heat loss by radiation by standing or lying close to each other so as to reduce the surface area exposed to the external environment (Bligh, 1998), and by seeking shelter (Mejdell & Boe, 2005), and increase absorbed radiation by changing body posture and orientation (Keren & Olson, 2007). For example, solar radiation may effectively diminish the cooling effect of low $T_a$ and high wind velocities.

Evaporative heat transfer is associated with the loss of water vapour from the body surface and respiratory system (Clark & McArthur, 1994). Evaporation and its cooling effect depend on the difference in water vapour pressure between the skin and $T_a$, and the exhaled and inhaled air, and on the respiration rate (Morgan, 1997b; Morgan et al., 1997). Evaporation of sweat is a controlled and effective mechanism of heat loss when $T_a$ is higher than $T_e$ (Clark & McArthur, 1994) and during exercise (Hodgson et al., 1994; Morgan et al., 2002). Evaporation also occurs insensibly (insensible water loss), causing continuous heat loss by evaporation, in the cold too (McArthur, 1991). Insensible water loss cannot be controlled for the purposes of thermoregulation, since it results from continuous diffusion of water molecules through the skin and respiratory surfaces regardless of $T_a$. At low $T_a$’s, insensible evaporation is almost
constant and has been observed to encompass about 20% of total heat loss (Morgan, 1996). The proportion of respiratory water loss may be relatively high since inhaled cold air contains little water vapour (Robinson et al., 2006). Wetting of the hair coat (Ousey et al., 1991; Kohn et al., 1999) and wind (Davenport, 1992) will further increase the cooling effect of evaporation. For example, Ousey et al. (1991) calculated that the warm wet surface of a horse at 25 °C loses heat at a rate of about 200 W/m² by evaporation.

2.2.6 Thermoneutrality and lower critical temperature

A general model of the relationship between \( T_a, T_b, \) HP and heat loss is presented in a thermoneutral diagram (Fig. 1). However, the true pattern of heat balance is more complex and dynamic because the actual values and relative positions of the curves depend on the animal’s species, age, plane of nutrition, acclimatization and environmental factors (Mount, 1973). Therefore, the model presents only general relationships between different quantities and zones. In addition, the zones of the model can be interpreted in a number of ways since they may be neutral in different respects. For example, the zone of least thermoregulatory effort is bounded at the colder limit by rising MR and at the warmer limit by increasing evaporative heat loss, and the zone of minimal metabolism is bounded on each side by rising MR. The zones may also be defined for particular purposes e.g. preferred thermal environment, animal productivity or optimal growth rate.

The TNZ is usually defined as the range of \( T_a \) at which a homeothermic endotherm does not have to expend more energy than

---

**Figure 1.** Diagrammatic representation of the relationship between ambient temperature, heat production, evaporative and non-evaporative heat loss and body temperature. A = zone of hypothermia, B = temperature of maximal metabolism, C = lower critical temperature, D = temperature of marked increase in evaporative heat loss, E = temperature of increase in metabolic rate, i.e. upper critical temperature, F = zone of hyperthermia, CD = zone of least thermoregulatory effort, CE = zone of minimal metabolism, i.e. thermoneutral zone (Mount, 1973).
that required for maintenance metabolism in order to compensate heat loss and to maintain constant $T_b$ (zone of minimal metabolism, C–E in Fig. 1) (Mount, 1973; Clark & McArthur, 1994). In this case, thermal balance is achieved by adjusting the rate of non-evaporative and evaporative heat loss through metabolically inexpensive adjustments in the thermal conductance of the body surfaces, including vasomotor responses, i.e. blood flow to the skin, postural changes and insulation adjustments, i.e. the thickness of the insulating air layer within the hair coat. However, the upper limit of the TNZ, i.e. the upper critical temperature, has also been defined on the basis of increasing evaporative heat loss (D in Fig. 1) (e.g. IUPS Thermal Commission, 2003). Therefore, the zone C–D is called the zone of least thermoregulatory effort (Mount, 1973). Between C and D, the line of non-evaporative heat loss is undefined since the rate changes as a result of peripheral vasomotor control to regulate the surface temperature. Above zone C–D, the rate of non-evaporative heat loss decreases because it is limited by the small temperature difference between the surface temperature of the horse and $T_s$ (Clark & McArthur, 1994; Morgan 1997b).

At and below the lower limit of the TNZ (C in Fig. 1), the body insulation is maximal (Morgan, 1995; Morgan et al., 1997). The non-evaporative heat loss, which occurs through convection, conduction and radiation, increases linearly with decreasing $T_a$ (towards B in Fig. 1) and the BMR is insufficient to balance increasing non-evaporative heat loss (Mount, 1973). Therefore, metabolic HP also has to increase in order to maintain a constant $T_b$ (zone B–C in Fig. 1). Below the lower critical temperature (LCT, point C in Figure 1), heat loss from the body surface in a standing animal occurs mainly by convection and radiation, because conduction is assumed to be negligible (Clark & McArthur, 1994) and evaporative heat loss is minimal and constant (Davenport, 1992; Morgan, 1995; Morgan et al., 1997). Both convection and radiation follow the temperature gradient (Langlois, 1994; Randall et al., 2001). However, it has been proposed that in still air conditions and especially in animals with an intact hair coat, convection may be of limited significance in the cold (Davenport, 1992). The temperature gradient can be reduced by increasing thermal insulation of the body, and consequently the LCT is shifted to lower $T_a$’s (Young, 1975). Increasing feed intake also lowers the LCT, because HP increases with increasing energy intake (Pagan & Hintz, 1986; Morgan, 1995; Verne et al., 1995; McDonald et al., 2002; Morgan et al., 2007). At a certain $T_a$ below the LCT (B in Fig. 1), HP is insufficient to compensate for constantly increasing non-evaporative heat loss, and the animal becomes hypothermic, i.e. the $T_b$ falls (A in Fig. 1) (Mount, 1973).

Recently, this classical view of the TNZ was elaborated by Arnold et al. (2004), who showed that metabolic HP decreased in red deer (Cervus elaphus) in the night and early morning hours during late winter as a response to an energetically challenging situation. This nocturnal hypometabolism is a previously unknown thermoregulatory response in large endothermic animals to periods of food shortage and harsh climatic conditions. It contributes to lower energy expenditure by lowering an animal’s defended $T_b$, which leads to reduced BMR and lower HP, meaning that the change in defended $T_b$ causes a corresponding change in the animal’s LCT. Therefore, the TNZ is well defined only for a given set-level of $T_b$. 

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2.3 Thermoregulation of horses in the cold

2.3.1 Lower critical temperatures for horses

The measured LCT values for horses are summarized in Table 2, which is an updated version of the summary presented in the review article by Cymbaluk (1994). The values vary considerably since many biological and environmental factors affect the LCT value. According to Cymbaluk (1994) and Morgan et al. (2007), age, breed, body condition, size, surface area to body mass ratio, physiological status, MR and acclimatization of the horse, and also quality of feeds, intensity of feeding, housing system, season and climatic factors affect the LCT value. The summary indicates that the LCT values are mainly determined by age and acclimatization.

Young horses generally have higher LCT values than mature horses (Table 2). Neonatal foals, in particular, have a high LCT, about 20 °C, because their body insulation is low and the ability for thermoregulation is less developed than in mature horses (Ousey et al., 1991, 1992, 1997). Due to their high LCT, neonatal foals are susceptible to cold after birth. However, there is considerable individual variation in the thermal insulation of neonatal foals which causes noticeable variation in the LCT (range 10 to 26 °C). Sick and premature foals are more susceptible to hypothermia than healthy foals, since they have a lower MR and minimal capacity for increase in metabolic HP (Ousey et al., 1997). Weanling and yearling horses are more cold-resistant than neonatal foals. The LCT values for cold-housed weanling and yearling horses vary in studies from –11 °C (Cymbaluk & Christison, 1989a) to 0 °C (Young & Coote, 1973; Cymbaluk et al., 1989a; Cymbaluk, 1990).

The LCT values for mature horses depend mainly on feed intake and the season to which the horses are acclimatized (Table 2). A cold-housed broodmare was reported to have a LCT of –1 °C in early winter and –9 °C in late winter (Young & Coote, 1973). The LCT was 5 °C in horses that were acclimatized to an indoor Ta of about 15 °C (Morgan, 1996, 1998; Morgan et al., 1997), and –15 °C in horses that were acclimatized to outdoor winter weather (McBride et al., 1985). The lower energy intake of the horses in the former study may also partly explain the difference. Minor breed differences have been found, ponies having a higher LCT than Quarter Horses (QH), Standardbred (SB), Thoroughbred (TB) and Warmblood (W) horses. Competition horses have a lower LCT value than maintenance horses due to their higher feed intake (Morgan et al., 2007). Clipping of the hair coat also affects the LCT value, elevating it by about 5 °C.

The LCT values in Table 2 are approximations and generalizations for horses, since there are large individual variations from the estimated values depending upon the factors mentioned at the beginning of this section. Moreover, the majority of these results (Young & Coote, 1973; McBride et al., 1985; Ousey et al., 1991, 1992, 1997; Morgan, 1996, 1997a, 1998; Morgan et al., 1997, 2007) only apply to dry, non-active horses in still-air conditions. Wind and wetting of the hair coat increase LCT values (McBride et al., 1985). Therefore, LCT values for horses outdoors possibly differ from the values given. It is also noteworthy that the methods used for assessing LCT in the field studies summarized in Table 2 varied greatly.
Cold acclimatization aims to shift the TNZ to lower $T_a$’s, which is achieved by increasing body insulation (Clarke, 1991) and by sustaining continuous extra HP (Cannon & Nedergaard, 2004). Usually, animals of large body size adjust body insulation in order to regulate heat exchange, and animals of small body size adjust HP (Phillips & Heath, 1995; Cannon & Nedergaard, 2004; Lovegrove, 2005). The mechanisms of acclimatization and acute responses to cold have been investigated in horses in a number of studies. Major thermal mechanisms are concerned with both

Table 2. Lower critical temperatures for horses (modified and updated from Cymbaluk, 1994). LCT = lower critical temperature, A = Arabian horse, BW = body weight, DE = digestible energy, MR = metabolic rate, P = Pony, QH = Quarter Horse, SB = Standardbred horse, TB = Thoroughbred horse, W = Warmblood horse, - = not known / studied.

<table>
<thead>
<tr>
<th>Age</th>
<th>Breed / type</th>
<th>LCT (°C) Mean Range</th>
<th>Method</th>
<th>Feed intake</th>
<th>Exposure type</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonate</td>
<td>TB, P</td>
<td>10, 20 -</td>
<td>Calculated$^a$</td>
<td>Suckle</td>
<td>Acute cold + heater</td>
<td>Ousey et al., 1991</td>
</tr>
<tr>
<td></td>
<td>TB, A</td>
<td>24 -</td>
<td>Calculated$^a$</td>
<td>Suckle/ suppl./ parenteral</td>
<td>Acute cold + heater / rug</td>
<td>Ousey et al., 1997</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>22 16 to 26</td>
<td>MR</td>
<td>Suckle</td>
<td>Acute cold</td>
<td>Ousey et al., 1992</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>19 13 to 23.5</td>
<td>MR</td>
<td>Suckle</td>
<td>Acute cold</td>
<td>Ousey et al., 1992</td>
</tr>
<tr>
<td>Weanling</td>
<td>SB</td>
<td>0 -</td>
<td>DE intake/ 100 kg BW</td>
<td>Restricted</td>
<td>Acclimatized</td>
<td>Cymbaluk, 1990</td>
</tr>
<tr>
<td></td>
<td>QH</td>
<td>-11 -</td>
<td>Gain/ feed ratio</td>
<td>$Ad$ libitum</td>
<td>Acclimatized</td>
<td>Cymbaluk &amp; Christians, 1989a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 -</td>
<td>DE intake/ 100 kg BW</td>
<td>$Ad$ libitum</td>
<td>Acclimatized</td>
<td>Cymbaluk &amp; Christians, 1989a</td>
</tr>
<tr>
<td>Yearling and</td>
<td></td>
<td>-9 to 0</td>
<td>Calculated$^b$</td>
<td>-</td>
<td>Acute cold/ acclimatized</td>
<td>Young &amp; Coote, 1973</td>
</tr>
<tr>
<td></td>
<td>SB</td>
<td>5 -</td>
<td>Total heat loss</td>
<td>Restricted</td>
<td>Acute cold</td>
<td>Morgan, 1996, 1998; Morgan et al., 1997</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>- 1.4 to 6.9</td>
<td>Calculated$^c$</td>
<td>Restricted</td>
<td>-</td>
<td>Morgan et al., 2007</td>
</tr>
<tr>
<td></td>
<td>TB</td>
<td>- 2.1 to 3.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>- 3.4 to 2.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^a$ based on body core temperature and body resistance, heat production, predicted MR and the volumetric specific heat of air

$^b$ based on heat production and rectal, skin and air temperatures

$^c$ based on body core temperature, heat flow, thermal insulation in tissue, coat and air, and evaporative heat loss
producing sufficient body heat and retaining it by the means of physiological and behavioural responses. Responses may be daily, seasonal or interannual (Clarke, 1991), and seem to differ to some extent between feral and domestic horses depending on nutritional status and available facilities.

### 2.3.2 Physiological responses

In the horse, physiological responses to cold have been studied from many different standpoints. The observed mechanisms and responses are summarized in Table 3, which is an updated version of the summary originally presented in the review article by Cymbaluk and Christison (1990). The mechanisms related to HP include T\(_{b}\), heart rate (HR), shivering, respiratory quotient (RQ), feed/energy intake, nutrient digestion and thyroid hormones secretion. Hair coat density and length, piloerection and vasconstriction are concerned with retaining body heat in the cold. Subcutaneous body fat and respiration rate are related both to HP and heat retention.

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Response</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metabolic rate</td>
<td>↑↔</td>
<td>Young &amp; Coote, 1973; McBride et al., 1985; Ousey et al., 1991, 1992, 1997; Arnold et al., 2006*</td>
</tr>
<tr>
<td>Body temperature</td>
<td>↓</td>
<td>Arnold et al., 2006*</td>
</tr>
<tr>
<td>Heart rate</td>
<td>↑↓</td>
<td>Ousey et al., 1992, Arnold et al., 2006*</td>
</tr>
<tr>
<td>Shivering</td>
<td>↑</td>
<td>Irvine, 1967; McBride et al., 1985; Ousey et al., 1991, 1992, 1997; Morgan, 1997b; Morgan et al., 1997; Mejdell &amp; Bøe, 2005</td>
</tr>
<tr>
<td>Feed /energy intake</td>
<td>↑</td>
<td>Cymbaluk &amp; Christison, 1989a; Cymbaluk et al., 1989a; Cymbaluk, 1990; Arnold et al., 2006*; Kuntz et al., 2006*</td>
</tr>
<tr>
<td>Weight gain</td>
<td>↓↔</td>
<td>Cymbaluk et al., 1989a; Cymbaluk, 1990</td>
</tr>
<tr>
<td>Dry matter intake</td>
<td>↓</td>
<td>Kuntz et al., 2006*</td>
</tr>
<tr>
<td>Gut passage time</td>
<td>↔↑</td>
<td>Cymbaluk, 1990; Kuntz et al., 2006*</td>
</tr>
<tr>
<td>Fiber digestion</td>
<td>↑</td>
<td>Cymbaluk, 1990</td>
</tr>
<tr>
<td>Phosphorus digestion</td>
<td>↓</td>
<td>Cymbaluk, 1990</td>
</tr>
<tr>
<td>Dry matter, energy, crude protein, calcium digestion</td>
<td>↔</td>
<td>Cymbaluk, 1990</td>
</tr>
<tr>
<td>Water intake</td>
<td>↓</td>
<td>Crowell-Davis et al., 1985; Cymbaluk, 1990; Kristula &amp; McDonnell, 1994</td>
</tr>
<tr>
<td>Thyroid hormones secretion</td>
<td>↑↔</td>
<td>Irvine, 1967; McBride et al., 1985; Mejdell &amp; Bøe, 2005</td>
</tr>
<tr>
<td>Hair density and length</td>
<td>↑↔</td>
<td>McBride et al., 1985; Cymbaluk, 1990; Neste, 2000; Mejdell &amp; Bøe, 2005</td>
</tr>
<tr>
<td>Piloerection</td>
<td>↑</td>
<td>Young &amp; Coote, 1973; Ousey et al., 1992</td>
</tr>
<tr>
<td>Vasconstriction</td>
<td>↑</td>
<td>Palmer, 1983; Mogg &amp; Pollitt, 1992; Morgan, 1997a</td>
</tr>
<tr>
<td>Respiration rate</td>
<td>↓</td>
<td>Dahl et al., 1987; Morgan, 1997b</td>
</tr>
</tbody>
</table>
Heat-producing mechanisms

Most of the physiological responses to acute or chronic cold observed in the horse (Table 3) are in accordance with general theories of thermoregulation. In mature horses (Young & Coote, 1973; McBride et al., 1985), yearling horses (Young & Coote, 1973) and neonatal foals (Ousey et al., 1991, 1992), the MR was found to increase as a response to acute cold, and in the foals the increase was accompanied by increased HR (Ousey et al., 1992). In cold-acclimatized horses, the MR was the same in early and late winter, probably indicating that mild winter weather did not provide sufficient stimulus to induce a change in the MR, or that acclimatization had already occurred prior to the measurement conducted in early winter (McBride et al., 1985). Furthermore, sick and premature neonatal foals are not able to increase metabolic HP which makes them susceptible to hypothermia (Ousey et al., 1997). It is also noteworthy that there may be large individual (Ousey et al., 1992) and breed (Ousey et al., 1991) differences in MR responses to cold.

A reverse metabolic response to cold than that occurring in domestic horses has been recently demonstrated in the Przewalski horse (Equus ferus przewalskii), which is an ancestral wild form of the domestic horse (Arnold et al., 2006) (Table 3). As an adaptation to low Ta and to decreased availability and quality of plant forage, Przewalski horses living under close-to-natural conditions reduced their energy expenditure during the winter by lowering Ti, which was accompanied by decreased metabolic HP and HR. Decreased Ta also lowers the temperature gradient between the body surface and Ti, and hence reduces heat loss. These seasonal changes were under endogenous control and prepared the animal in advance for predictable seasonal changes of climate and of availability and quality of food. Whether such an adaptation mechanism occurs in domestic horses is not known.

An increase in metabolism by means of shivering has been observed in domestic horses at low Ta’s (Table 3). Visible shivering occurred in mature horses (McBride et al., 1985; Morgan, 1997b; Morgan et al., 1997) and neonatal foals (Ousey et al., 1991, 1992, 1997) during acute cold exposure and in mature horses during long-term cold exposure in rainy weather (Irvine, 1967; Mejdell & Bøe, 2005). In neonatal foals, shivering was accompanied by an increased RQ, which indicated that the foals utilized muscle and liver glycogen as an energy source by shivering (Ousey et al., 1991, 1992, 1997). The results obtained by Ousey et al. (1991, 1992, 1997) on the existence of shivering in neonatal foals support the general assumption that NST does not exist in the horse (see Cymbaluk, 1994). However, the presence of NST has not been studied in the horse (Cymbaluk & Christison, 1990; Cymbaluk, 1994). Since NST has been observed in some other large, newborn endothermic animals (calves: Alexander et al., 1975; Vermorel et al., 1983 and reindeer: Markussen et al., 1985; Soppeia et al., 1991, 1992), NST would be worth studying in the horse, too.

At Ta’s lower than the LCT, extra energy from feed is needed in order to increase metabolic HP (NRC, 2007). This extra demand for feed is called climatic energy demand (CED) (MacCormack & Bruce, 1991). Horses have been reported to need about 0.2 to 2.5 % more energy for maintenance per 1 °C decrease in Ta below the LCT (Young & Coote, 1973; McBride et al., 1985; Cymbaluk et al., 1989a; Cymbaluk, 1990). Body size is very important feature in determining LCT and CED (AAPCA, 1991; MacCormack & Bruce, 1991; Morgan, 1995). Small-sized horses have higher LCT values and need propor-
tionally more additional feed, because their heat loss in the cold is relatively greater than in larger horses. In addition, good body insulation (Young & Coote, 1973; Ousey et al., 1992; Morgan, 1997a) and high energy intake (Morgan, 1995; Morgan et al., 2007) affect cold resistance and result in a lower LCT. If CED is not taken into account in the plane of feeding, the weight gain of growing horses declines (Cymbaluk et al., 1989a; Cymbaluk, 1990). When the rate of feeding is increased or $T_s$ rises, compensatory growth (i.e. a growth spurt) may occur (NRC, 2007). The CED of a horse can be efficiently reduced by using a rug or by providing a shelter (AAPCA, 1991; MacCormack & Bruce, 1991).

However, the results concerning voluntary feed and energy intake of domestic horses in the cold are contradictory (Cymbaluk & Christison, 1989a; Cymbaluk et al., 1989a) (Table 3). It seems that horses do not invariably increase feed intake as $T_s$ decreases (NRC, 2007). This may indicate that daily $T_s$ fluctuations under cold conditions have little effect on energy intake by cold-acclimatized, adequately fed horses (Cymbaluk & Christison, 1989a), but may also be a consequence of different environmental or biological factors in the studies, e.g. differences in body insulation, and reflect inter-individual variation in thermoneutrality. However, feral Przewalski horses have been reported to generally voluntarily reduce dry matter (DM) and energy intake in late winter (Kuntz et al., 2006). Reduced DM intake suggested a shift towards body energy reserves as the major metabolic fuel, which was supported by a remarkable decrease in body condition scores (BCS) of the horses during the winter. The shift towards the use of body energy reserves may be an adaptive response to cold when the energetic and time costs of foraging and digestion outweigh the energy intake. Also in other studies of horses living under close-to-natural conditions, BCS has been found to decrease during the winter (domestic horses: Dieterich & Holleman, 1973; Przewalski horses: Berger et al., 1999; Kuntz et al., 2006). This annual change in BCS does not occur in domestic, outdoor-housed horses when the horses are fed good-quality feeds in sufficient amounts or ad libitum (see Cymbaluk & Christison, 1989a; Mejdell & Bae, 2005). However, individual differences may occur when horses are group-housed, because higher ranking individuals have been reported to gain weight in the wintertime, while subordinates lose weight due to limited access to food (Ingólfsdóttir & Sigurjónsdóttir, 2008).

Cold exposure may affect nutrient digestion (Cymbaluk, 1990) (Table 3). Przewalski horses were reported to improve nutrient absorption by increasing gut passage time in late winter (Kuntz et al., 2006). Gut passage time was not related to concentrations of nutrients in DM, but rather was related to photoperiod. Kuntz et al. (2006) concluded that this mechanism, i.e. an endogenous cycle in gut passage time regulated by photoperiod, adapts the gut function and hence the digestive strategy to meet the highly predictable seasonal changes in food quality. However, in domestic weanling horses, cold housing environment did not affect feed retention time (Cymbaluk, 1990). Instead, fibre digestibility increased and phosphorus digestibility decreased. It was speculated that increased fibre digestibility may have resulted in higher HP, but cold housing did not affect DM, energy, crude protein or calcium digestibility. It seems that a cold housing environment generates an increased demand mainly for energy (NRC, 2007). However, it should be noted that in the study by Cymbaluk (1990), the cold effects on diet digestibility may have been confounded by...
age effects and by the composition and physical characteristics of the diet.

Feed composition may also affect HP, and thus the type of feed may help the horse to cope during cold weather (NRC, 2007). The heat increment (HI) of digestion, i.e. the amount of metabolizable energy (ME) that is converted to heat during the digestive processes and the metabolism of absorbed nutrients (Sjaastad et al., 2003), represents 10 to 30 % of the feed ME in the horse (Frape, 1998). The HI increases during eating (Vernet et al., 1995), with increasing feed intake (Pagan & Hintz, 1986; Vernet et al., 1995) and protein content of feed (Sjaastad et al., 2003), and is greater for forages than concentrates (Vermorel et al., 1997; Frape, 1998). Therefore, forages are commonly fed *ad libitum* for outdoor housed horses to allow them to eat to their energy demands (NRC, 2007).

In cold-haired horses, attention should also be paid to adequate water intake, since horses have been reported to decrease water intake in the cold (Crowell-Davis et al., 1985; Cymbaluk, 1990) (Table 3). Horses also drink less cold than warm water during cold weather (Kristula & McDonnell, 1994). Insufficient water intake predisposes horses to dehydration (Houpt et al., 2000) and may lead to impaction colic (Kristula & McDonnell, 1994).

Endocrinological responses to cold are difficult to interpret, since many factors, e.g. photoperiod and age, breed, body weight (BW), diet carbohydrate content, exercise, gender and pregnancy of the horse (Irvine, 1967; Glade & Reimers, 1985; Cymbaluk, 1994; Fazio et al., 2007), affect the secretion of thyroid hormones. Accordingly, the thyroid hormones responses of horses to cold are contradictory (Table 3). In some studies, $T_A$ had no effect on the thyroid hormones secretion rate (McBride et al., 1985; Mejdell & Boe, 2005), and in some studies the secretion rate increased as $T_A$ decreased (Irvine, 1967; McBride et al., 1985). This signifies that horses do not invariably respond to low $T_A$ by increasing thyroid hormones secretion (Cymbaluk, 1994; Mejdell & Boe, 2005), and, therefore, that thyroid hormones concentrations may not be reflective of acclimatization to cold (McBride et al., 1985) as presented in animal physiology textbooks (e.g. Sjaastad et al., 2003). Accordingly, the thyroid hormones responses of horses to cold should be interpreted with caution.

**Heat-retaining mechanisms**

As mentioned above, in addition to being the body’s energy reserve, subcutaneous fat is protective in cold due to its low thermal conductivity and poor blood supply (Davenport, 1992). The distribution of fat may be adjusted by cold acclimatization (Langlois, 1994). Fat is dispersed more evenly over the body surface instead of being concentrated in particular areas as in hot conditions.

Body heat can also be retained with the aid of increasing hair coat density and length, which is a chronic, slow response to winter caused mainly by photoperiodism (Cymbaluk & Christison, 1990; Cymbaluk, 1990, 1994). Hair growth in horses is cyclic and the winter coat is kept for about nine months (Talukdar et al., 1972). Accordingly, hair coat density and length have been reported to increase during the autumn and winter (Cymbaluk, 1990; Neste, 2000; Mejdell & Boe, 2005) (Table 3). In addition to photoperiod, $T_A$ also seems to affect hair growth. A cold housing environment was noted to produce a higher hair coat weight than a warm housing environment (Young & Coote, 1973; Cymbaluk, 1990), and the winter coat was shed later in cold-housed horses. In cold conditions, the coat may also consist of longer, finer and more poorly medullated fibres than in warm conditions, which increases coat insulation
(Scott, 1988). Also hormones and horse breed affect coat growth (Scott, 1988; Cymbaluk, 1994; Cymbaluk & Christison, 1990; Neste, 2000). Therefore, there is considerable individual variation in the thermal insulation of the coat (Talukdar, 1972; Ousey et al., 1992), and, for example, adequately fed cold-housed horses do not inevitably grow a thick winter coat (Young & Coote, 1973; McBride et al., 1985). The thermal insulation of the coat is decreased by rapid body movements during shivering (Ousey et al., 1992) and by clipping of the hair coat (Morgan, 1997b; Morgan et al., 2002). Clipping is common especially in competition horses since it facilitates heat dissipation from the body during exercise.

Piloerection of the hair and peripheral vasoconstriction, which increase body insulation, are rapid and effective heat-retaining mechanisms (Mogg & Pollitt, 1992; Cymbaluk, 1994). Piloerection has been studied in two studies (Table 3). Piloerection increased coat depth by 0.3 to 1.4 cm in neonatal foals (Ousey et al., 1992) and 10 to 30% in mature horses (Young & Coote, 1973). Peripheral vasoconstriction, and hence a decrease in surface temperatures, has been generally observed in horses as a response to low T_a (Palmer, 1983; Mogg & Pollitt, 1992; Morgan, 1997a). However, irregular spontaneous increases in surface temperatures were observed at low T_a (Mogg & Pollitt, 1992). This was probably attributed to periodic vasodilator activity, which may have functioned to warm the peripheral tissues.

Decreased respiration rate has been observed in horses during and after exercise in response to acute cold (~25 °C), which was possibly associated with the need to reduce heat dissipation in the cold (Dahl et al., 1987) (Table 3). Respiration rate was also lower in clipped horses than in horses with an intact hair coat in the cold, which was also interpreted as a response to reduce heat loss from the respiratory system (Morgan, 1997b). The respiratory minute volume, which is a function of respiration rate and tidal volume, was not measured, but breathing of the horses appeared deep and slow in the cold.

### 2.3.3 Behavioural responses

Behavioural changes are important thermoregulatory mechanisms (Høst et al., 1997), and therefore play an important role in the ability of the horse to thrive under varying climatic conditions (McDonnell, 2003). Behavioural mechanisms, too, can be divided into heat-producing and heat-retaining mechanisms, and are summarized in Table 4, which is an updated version of the summary originally presented in the review article of Cymbaluk and Christison (1990). Mechanisms related to HP include temporary activity, general activity and eating, and those related to retaining body heat include shelter- and comfort-seeking, general activity and resting. Shelter- and comfort-seeking mechanisms include the seeking of warmer microclimates (Høst et al., 2007) and the reduction of exposed surface area by changing body shape or orientation, which encompasses standing with the hindquarters into the wind or rain or into a natural windbreak, basking (resting in warm, sunny areas during cold weather, McDonnell, 2003) and huddling (lying with bodies in contact, Sjøaasdal et al., 2003) (McDonnell, 2003).

Shelter- and comfort-seeking behaviour has been observed both in domestic (Gunnarsson & Ingvarsson, 1995; Michanek & Ventorp, 1996; Mejdell & Boe, 2005; Høst et al., 2007; Ingólfsdóttir & Sigurjónsdóttir, 2008) and feral (Duncan, 1985) horses in winter (Table 4). In domestic horses, the main motive to use the shelter is probably the need for a comfortable lying place, whereas the need for weather protection is probably a secondary motive.
In addition to low $T_a$ (Duncan, 1985; Mejdell & Bøe, 2005), also rain and/or wind and drizzle increase the use of shelter (Michanek & Ventrop, 1996; Mejdell & Bøe, 2005; Ingólfsdóttir & Sigurjónsdóttir, 2008). Huddling as a means of retaining body heat has not been extensively studied in the horse, although it has been suggested that, by standing close and exposing the surface areas to each other, the confronting surface areas of the horses have the same temperature, and non-evaporative heat loss decreases (Morgan, 1996). To my knowledge, only Gunnarsson and Ingvarsson (1995) have mentioned that loose-housed weanling horses tended to lie close to each other, and Ingólfsdóttir and Sigurjónsdóttir (2008) noted that Icelandic outdoor-housed horses formed tight groups when the weather was bad. Basking has also not been studied extensively in the horse, being mentioned in only one study (see Mejdell & Bøe, 2005).

Horses may also modify their time budget in order to adjust themselves to prevailing climatic conditions (Langlois, 1994) (Table 4). Feral horses have been reported to increase the time spent eating and resting, and to reduce locomotor activity in autumn and winter (Duncan 1980, 1985; Berger et al., 1999; Mejdell & Bøe, 2005; Arnold et al., 2006). In Przewalski horses, lower locomotor activity level in winter has recently been proven to be related to lower MR, and hence to lower energy expenditure (Arnold et al., 2006). However, van Dierendonck et al. (1996) reported that despite of a long, severe winter, the time budget of Przewalski horses did not vary between seasons. Contradictory results in feral horses may be due to differences in sampling procedures and to local availability and quality of food. However, in domestic horses, feeding time and activity did not invariably change in the cold when the horses were acclimatized to the cold and fed sufficiently (see Mejdell & Bøe, 2005). Short-term behavioural changes, e.g. restlessness and temporary activity, may also occur in response to acute cold and adverse weather (see McBride et al., 1985; Morgan, 1997b; Jørgensen & Bøe, 2007).
3. OBJECTIVES

At temperatures colder than the LCT, a horse has to increase its metabolic HP in order to maintain its $T_a$. Therefore, a cold housing environment may have significant effects on the energy needs of a horse. Loose housing, which is expected to provide a more natural housing environment for weanling horses than traditional box stabling, exposes horses to prolonged periods of low $T_a$ and changing weather conditions. Horses attain 60% of their mature weight and 90% of their mature height during the first year of life, i.e. their growth rate is very high during the first winter. Therefore, the following questions can be raised: How much does a cold housing environment increase the energy needs of weanling horses? Is it possible to maintain normal growth rate and body condition in a loose housing system if CED is high? Are some horse breeds more cold resistant than others and thus probably more suitable for loose housing? Do horses acclimatize to a cold housing environment by insulation changes? Do they use behavioural thermoregulation in the cold? In addition, there is no knowledge as to whether loose housing actually provides horses with an opportunity to satisfy their behavioural needs.

The general objective of this study was to examine the suitability of a loose housing system as a winter environment for weanling horses in a cold climate by studying the effects of a cold housing environment on weanling horses. In particular, the effects on behaviour, nutrition, growth and cold resistance were studied. In addition, the aim was to produce information for general counseling and education.

The hypotheses underlying the experimental scheme of this study were: 1) The loose housing system was assumed to provide the horses with an opportunity to fulfill their behavioural needs, i.e. their behavioural patterns and circadian rhythm were expected to resemble that of feral and pastured horses. In addition, it was hypothesized that the horses would be relatively active because of the 24-h opportunity for exercise. 2) It was expected that the horses would use behavioural adjustments to acclimatize to the cold housing environment. It was also assumed that low $T_a$ would affect the radiative heat loss and energy needs of the horses. The horses were expected to grow normally and maintain their BCS when the increased energy need is taken into account in the feeding. 3) It was expected that there would be differences in cold resistance between different horse types.

The more detailed aims of the studies were:

- To determine the time budget and circadian rhythm of weanling horses in a loose housing system, and to investigate the effect of weather conditions on behaviour (I).
- To observe the energy intake and growth of weanling horses in a loose housing system (II).
- To compare the rate of radiative heat loss and thermal insulation of different horse types during different seasons (III).
- To evaluate the thermoregulatory capacity of cold-acclimatized, loose-housed weanling horses by determining their LCT (IV).
- To measure horse activity under different management environments ($U_1$). This examination was conducted in order to assess the suitability of global positioning system (GPS) technology for recording horse activity, and to verify the activity results of study I.
- To complete the measurements of thermal insulation done in study III ($U_2$).
4. MATERIALS AND METHODS

This section presents concise versions of the materials and methods described more fully in the original articles (I-IV). The materials and methods of the previously unpublished studies (U₁ and U₂) are described in more detail.

4.1 Animals and housing

The studies were conducted at the Vocational Institute of Ylä-Savo, in Kiuruvesi, Finland over the years 1998–2000 (III) and 2002–2006 (I, II, IV, U₁, U₂) (Table 5). The horses in the experiments were mainly weanling horses, but also foals, yearling horses and mature horses were used. The horses were classified into four types according to breed: light (L), warmblood (W), coldblood (C) and pony (P) types. The horses of type L were SB horses, type W were Danish and Polish warmblood horses, type C were Finnish coldblood horses (FC) (i.e. Finnhorses) and type P were Connemara and New Forest ponies.

The horses were housed in an experimental loose housing/paddock system (I, II, IV, U₁), in a conventional stable in single, loose boxes (III, U₂), in a group box/paddock system (U₁) or kept in a pasture (U₁) (Table 5). The unheated, insulated loose house consisted of two identical sleeping halls (45 m²), entrance shelters (8.5 m²) and paddocks (0.08 ha) (described in more detail in I). The weanling horses were weaned and brought to the loose housing system in October. The horses had free access to the sleeping hall and paddock. In the daytime, the horses were also able to use a large paddock (0.64 ha). There was natural ventilation in the halls and the bedding used was a mixture of peat and straw.

Table 5. Summary of the animals and facilities in the studies. C = coldblood horse type, L = light horse type, P = pony type, W = warmblood horse type.

<table>
<thead>
<tr>
<th>Study</th>
<th>I, II</th>
<th>III</th>
<th>IV</th>
<th>U₁</th>
<th>U₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Season</td>
<td>Winter</td>
<td>Late summer / autumn / winter</td>
<td>Winter</td>
<td>Winter / summer</td>
<td>Winter</td>
</tr>
<tr>
<td>n</td>
<td>10</td>
<td>18</td>
<td>9</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Horse type</td>
<td>L (4+3)</td>
<td>L (4+0)</td>
<td>L (3+3)</td>
<td>L (0+1)</td>
<td>L (2+2)</td>
</tr>
<tr>
<td>(♂+♀)</td>
<td>C (1+2)</td>
<td>C (4+0)</td>
<td>C (1+3)</td>
<td>C (1+2)</td>
<td>C (2+2)</td>
</tr>
<tr>
<td></td>
<td>W (4+0)</td>
<td>W (4+0)</td>
<td></td>
<td></td>
<td>W (4+0)</td>
</tr>
<tr>
<td></td>
<td>P (3+3)</td>
<td></td>
<td></td>
<td></td>
<td>P (2+2)</td>
</tr>
<tr>
<td>Age</td>
<td>Weanling</td>
<td>Mature</td>
<td>Weanling</td>
<td>Foal</td>
<td>Mature</td>
</tr>
<tr>
<td></td>
<td>Weanling</td>
<td>Yearling</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Management conditions</td>
<td>Loose house + paddock</td>
<td>Box stable + paddock</td>
<td>Loose house + paddock</td>
<td>1) Loose house + paddock</td>
<td>Box stable + paddock</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2) Group box + paddock</td>
<td>3) Pasture</td>
<td></td>
</tr>
</tbody>
</table>
T<sub>a</sub> in the sleeping halls was on average 4 °C higher than the outdoor T<sub>a</sub>. The horses housed in the box stable were kept out in the paddock for a maximum of 10 h per day (III, U<sub>2</sub>). The horses in the pasture were kept out for 24 h per day (U<sub>1</sub>). The indoor and outdoor T<sub>a</sub> (I, III, IV, U<sub>1</sub>), RH (I, IV, U<sub>1</sub>) (HM34C, Vaisala Oyj, Helsinki, Finland) and outdoor wind speed (I, U<sub>1</sub>) (SKYWATCH® Meteos, JDC Electronic SA, Yverdon-les-Bains, Switzerland) of the study site were measured on a regular basis during the experimental days (see Table 2 in I, Table 3 in IV). Cloudiness and 24-h precipitation were also determined (I, U<sub>1</sub>) (see Table 2 in I). In study II, daily T<sub>a</sub>’s were obtained from the meteorological recording station at Vieremä (Finnish Meteorological Institute), located about 30 km from the study site (see Fig. 2 in II).

In study U<sub>1</sub>, average T<sub>a</sub> (±SD) during the experimental days in the summer was 20±2 °C during the measurements conducted on the foals, and 18±3 °C during the measurements conducted on the yearling horses. In the winter, T<sub>a</sub> on the experimental days was −6±3 °C during the measurements conducted on the weanling horses in the loose housing system, and −3±2 °C during the measurements conducted on the weanling horses in the group box/paddock system. The sky was partly clouded and the weather was mainly dry, except for a few short snowfalls during the winter examinations.

4.2 Animal care
The weanling horses housed in the loose housing system (I, II, IV, U<sub>1</sub>) were fed timothy hay ad libitum. Hay was used as the main forage because it was easy to handle and did not freeze in the winter. Hay was placed in off-the-ground feeding troughs (I, II) or in feeding enclosures (IV, U<sub>1</sub>) outside the sleeping halls. Hay was supplemented individually with controlled amounts of silage (I, II) and concentrates (protein, concentrates, and vitamin and mineral supplements) (I, II, IV, U<sub>1</sub>) in order to ensure adequate nutrient intake. Silage was fed twice a day at 06:00 and 16:00, and concentrates three times a day at 06:00, 10:30 and 16:00. The horses were tied to a wall beside feed buckets inside the halls during the feeding of concentrates and silage. Salt blocks and automatic water troughs were located inside the halls. The horses housed in the box stable (III, U<sub>2</sub>) were fed four times a day. Hay was fed at 07:00 and 10:00 when the horses were outdoors in the paddock, and in the stable at 16:00 and 20:00. Concentrates were fed in the stable at 06:00 and 16:00. The horses in the pasture had free access to water, salt blocks and mineral supplement (U<sub>1</sub>). The feeds used in the studies were conventional horse feeds used at the Vocational institute.

All the horses had been vaccinated against influenza and treated regularly against internal parasites. The rectal T<sub>b</sub> of the horses was checked every morning except when the horses were in the pasture.

4.3 Behavioural measurements
The time budget, circadian rhythm and effect of weather conditions on horse behaviour in the loose housing system were investigated (I). The horses were housed in two groups (five horses in each group), which spent the evenings and nights (16:00–06:00) separated on their own sides of the facility. Both groups had free access to a large paddock between the hours of 06:00 and 16:00 and were then able to use both sides of the facility. In the results, the groups were combined. The behaviour of the horses was observed from December to March. Observations, a total of 23 24-h periods, were performed by video recording (evenings and nights) and by direct visual observations (daytime). The maximum number of observational days in a month
was ten days and the minimum three days. The locations of the horses in the loose housing system were noted every 15 min along with the behaviour performed at that time (instantaneous sampling, Martin & Bateson, 1993). The behaviours recorded were resting, eating and activity, which were further classified in more detail (resting: standing or lying with or without huddling; eating: eating hay, concentrates/silage or drinking; activity: standing, walking, running, playing, other) (for definitions see Table 1 in I).

The daily distance travelled by the horses under different management conditions was measured using GPS technology (U₁). Mobile software (MapHit® Sport, Karttaikkuna Oy, Sulkava, Finland) was installed in mobile phones (Nokia 3230, Nokia Oyj, Espoo, Finland). GPS receivers (BT GPS X-MIN™, RoyalTek Company Ltd., Tao Yuan City, Taiwan) and mobile phones were placed in capsules that were attached to the horses’ halters (weanling and yearling horses) or to harnesses that were fitted on the horses’ back (foals). The horses were accustomed to carrying the devices on their halters or on their backs. The mobile software measured the distance (km) that the horses travelled as well as the average speed (km/h) in six-hour periods starting at 10:00. The measurements were conducted as follows:

1. Three-month-old foals in pasture in the summer (n=2, 4 d)
2. Yearling horses in pasture in the summer (n=2, 7 d)
3. Weanling horses in a loose housing system in the winter (n=4, 6 d)
4. Weanling horses in a group box (nights) and paddock (daytime) in the winter (n=2, 5 d)

The examinations were conducted using two horses, but altogether there were three foals in the pasture (1.4 ha) with their dams in the first examination (U₁). In the second examination, there were a total of three yearling horses and three mature horses in the pasture (1.3 ha). In the third examination, there were four weanling horses in the loose housing system with 24-h access to a paddock (0.08 ha) and daytime access to a large paddock (0.64 ha). In the last examination, three weanling horses were housed indoors in the group box (45 m²) during the nights (16:00–06:00) and activity was measured in the daytime (07:00–16:00), when the horses had free access to a large paddock (0.64 ha).

4.4 Energy intake and growth

The effect of a cold loose housing environment on the ME intake and growth of the weanling horses was studied between November and March (II). The energy need was determined on the basis of the performance of the horses during the experiment. ME intake was compared to the prediction of energy intake for 6-12-month-old horses expected to reach a mature BW of 500 kg, which was based on the MTT 2006 and SLU 2004 requirements. The LCT of the weanling horses was determined on the basis of the ME requirements for horses with a specific thermal resistance (moderate BCS and winter hair coat).

The feeds used in study II are described in detail in Table 6. The nutrient compositions of hay, silage and oats were analysed by the regional laboratory of Valio Oy (Lapinlahti, Finland) by the standard NIR-method (Nousiainen et al., 2003). The nutrient compositions of protein (Racing Protein, Suomen Rehu Oy, Helsinki, Finland) and concentrate (Mella leseleike, Suomen Rehu Oy, Helsinki, Finland) supplement were analysed by the laboratory of Suomen Rehu Oy (Turku/Seinäjoki, Finland) by the standard methods (Ministry of Agriculture and Forestry, 2006). The laboratories determined the feed values of the forages and concentrates by using MTT
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Formulas and feed tables. The nutrient composition of mineral and vitamin supplement (Steel Joint, Oy Steel Joint Ltd, Lahti, Finland) was analysed by Outokumpu Mining Services (Outokumpu Oyj, Espoo, Finland) by the standard x-ray fluorescence spectroscopy (XRF) method.

At the beginning of the study, the horses were given a sufficient diet to supply the nutrient requirements (MTT, 2006) II. Group hay intake was daily determined by measuring hay refusals every morning before the subsequent distribution. The amounts of silage and concentrates fed were adjusted according to voluntary hay intake; the nutrients received from hay and the amounts of other feeds given were calculated so that the nutrient requirements of ME, digestible crude protein, calcium, phosphorus and lysine were met. Refusals of silage and concentrates were determined and deducted from consumption.

The BCS of the horses was assessed once a week on a subjective scale from one (poor) to nine (extremely fat) (Henneke et al., 1983) II. Moderate BCS, i.e. a score of 5, was regarded as an indicator of adequate energy intake and was the target score. Thus, ME intake was adjusted individually according to BCS of the horses by changing the amount of silage and/or concentrates fed. Nutrient intake was calculated using Hopti software (Equine Information Centre, Kuopio, Finland). During the experiment, the diets were revised on average twice a month. At the same time, the intakes of other nutrients (digestible crude protein, calcium, phosphorus and lysine) were adjusted so that at least minimum nutrient requirements were met.

The horses were measured weekly for BW and wither height II. In addition, the average daily gain (ADG) was determined. The wither height measurements were started on the first day of the study and the BW measurements in December due to technical problems with the weighing scale. The growth of the SB horses was compared with the growth data presented in Sandgren et al. (1993), and the growth of the FC horses with the growth data presented in Saastamoinen and Koskinen (1993), and Ahtila and Saastamoinen (2005).

4.5 Thermographic examinations

In the thermographic examinations, the cold resistance of different horse types (III) and the thermoregulatory capacity of cold-acclimatized weanling horses (IV) were evaluated on the basis of radiative heat loss.

Table 6. Nutrient composition and feed values of feeds used in study II (dry matter basis).

<table>
<thead>
<tr>
<th>Feed</th>
<th>Hay (g/kg)</th>
<th>Silage (g/kg)</th>
<th>Oats (g/kg)</th>
<th>Protein supplement (g/kg)</th>
<th>Concentrate supplement (g/kg)</th>
<th>Mineral and vitamin supplement (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter</td>
<td>830</td>
<td>600</td>
<td>860</td>
<td>890</td>
<td>880</td>
<td>850</td>
</tr>
<tr>
<td>Metabolizable energy (MJ/kg)</td>
<td>9.0</td>
<td>9.8</td>
<td>12.3</td>
<td>13.1</td>
<td>14.6</td>
<td></td>
</tr>
<tr>
<td>Digestible crude protein (g/kg)</td>
<td>93</td>
<td>130</td>
<td>126</td>
<td>202</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Calcium (g/kg)</td>
<td>3.0</td>
<td>7.6</td>
<td>0.8</td>
<td>11.2</td>
<td>4.6</td>
<td>164.7</td>
</tr>
<tr>
<td>Phosphorus (g/kg)</td>
<td>2.4</td>
<td>3.2</td>
<td>3.5</td>
<td>4.5</td>
<td>1.0</td>
<td>0.4</td>
</tr>
</tbody>
</table>

*Consisting of wheat bran, sugar beet and molasses.
Mature horses were used in the examination of cold resistance of different horse types instead of weanling horses in order to exclude the effect of growth on the results (III).

The thermographic examinations in the mature horses were carried out during different seasons: late summer, autumn and winter (III). The horses represented four different types: L (BW 459±69 kg, mean±SD), W (604±25 kg), C (548±21 kg) and P (323±27 kg). The examinations were conducted in August (15 °C) and October (2 °C) with all horse types, in March (–12 °C) with type P, and a year later in March (–8 °C) with types L, W and C. Thermal images of the weanling horses were taken at 0 °C, –9 °C, –16 °C and –23 °C during the winter (IV). The examinations were performed in stationary conditions in a cold indoor riding arena (III) or storage area (IV), which protected the horses from wind, sun and rain. The thermal arena and the storage area was the same as the outdoor Ta, to which the horses were acclimatized.

Thermal images were taken with an Inframetrics 600 camera (FLIR Systems, Inc., Portland, OR, USA) (III) and a ThermaCam PM595 (FLIR Systems, Inc., Portland, OR, USA) (IV). A general view was taken from the non-mane side of the horses at a distance of 8 m. The images were analysed at Satakunta Polytechnic (Pori, Finland). The rate of radiative heat loss (W/m²) was calculated from the trunk and neck (Fig. 2) by the following equation:

\[ P = \varepsilon \sigma (T_s^4 - T_a^4) \]

where, \( P \) = net emitted power (W/m²), \( \varepsilon \) = emissivity 0.95, \( \sigma \) = Stefan-Boltzmann constant \( 5.67 \times 10^{-8} \) Wm²K⁻⁴, \( T_s \) = surface temperature (K), \( T_a \) = ambient temperature (K), \( \bar{\ldots} \) = average of measuring points.

Thermal insulation of the body was...
evaluated at the same time as the thermographic examinations (III, IV), because thermal insulation affects radiative heat loss. Thermal insulation was assessed on the basis of BCS (see details above), which indicates the amount of subcutaneous fat in the body, and hair coat weight of the horses. Hair samples were taken from the mid-neck about 5 cm below the base of the mane using a coat clipper (Oster Golden A5®, Oster Professional Products, McMinnville, TN, USA). The sample area was determined and the samples were oven-dried at 40 °C for 12 h and weighed. The hair weight per area unit was calculated.

For the mature horses (III), complementary hair weight measurements were conducted three years later in December in order to obtain a complete hair growth curve for horses in winter (U2) (Table 5). Some of the horses used for the complementary measurements were the same as those used for the thermographic examinations (III). The horses that were no longer available were replaced by horses representing the same horse type.

4.6 Statistics and the presentation of results

The statistical software SPSS 10.0 (III), 11.0 (IV) and 14.0 (I, II) for Windows (SPSS Inc.) were used for the statistical analyses. In addition to the descriptive behavioural results in study I, the effects of Tᵢ, RH, wind speed, precipitation and cloudiness on behavioural parameters were analyzed by Linear Regression.

Average weekly nutrient intakes (ME, digestible crude protein, calcium and phosphorus) of the weanling horses were compared with nutrient requirements by the One-Sample t-Test (II). BCS was compared with the target BCS by the Wilcoxon Signed-Rank test. Since the comparisons were made separately for repeated measurements, the p-values were multiplied by the Bonferroni correction. The effect of time and Tᵢ on total (MJ/d) and mass-specific (MJ/100 kg BW/d) ME intake was tested using the Linear Mixed Model (LMM) (see materials & methods in II for statistical models), where Tᵢ was included as a continuous or categorical variable. The latter analysis with Tᵢ’s in two categories, warm (Tᵢ > -11 °C) and cold (Tᵢ < -11 °C), was performed to compare my own results to Cymbaluk and Christison’s (1989a) estimation of LCT (~11 °C) for light horse weanlings. Their horses were kept under comparable climatic and management conditions, and the LCT was also defined on the basis of feed intake. It should be noted that, since the horses in my study were group housed, daily hay intake values were calculated from group hay intake and were uniform for all the horses. Variation in total nutrient intakes (consisting of nutrient intakes from hay, silage and concentrates) is therefore slightly underestimated.

The differences in the rate of radiative heat loss and hair weight between different horse types during and between different seasons were tested using the Kruskal-Wallis and Mann-Whitney U tests (III). The differences in the radiative heat loss from the various body regions during and between seasons were tested using the Friedman and Wilcoxon signed-rank tests. The effect of Tᵢ on the rate of radiative heat loss of weanling horses and the differences in radiative heat loss from the various body regions at different Tᵢ’s were tested using the LMM (IV). The model calculated estimated marginal means of the radiative heat loss (±SE), where the effect of time-dependent covariates (metabolic BW [kg⁰.⁷⁵] and hair weight) was standardized. The effects of metabolic BW, BCS and hair weight on the rate of radiative heat loss were tested using Linear Regression. In the results section of this thesis, the original values of the rate of radiative heat loss
(mean±SD) (IV) are used in Fig. 7, i.e. the effects of time-dependent covariates are not standardized, since it enables the comparison of the radiative heat loss of the weaning horses (IV) with that of the mature horses (III).

The results of the activity measurements (U₁) were not tested statistically because of the small number of horses in the measurements. The daily average distance travelled and speed were calculated.
5. RESULTS

This section presents a summary of the main results described more fully in the original articles (I-IV). New syntheses of the results are also included. The results of the previously unpublished studies (U₁ and U₂) are presented in more detail.

5.1 Behavioural patterns of horses

5.1.1 Time budget and circadian rhythm
The horses spent most of the day, about 37 %, on ingestive behavioural patterns (eating hay, concentrates, silage or drinking) (Fig. 3) (I). The remaining time was divided equally between resting (standing or lying) and being active (standing, walking, running, playing, other). The horses rested mostly in a lying position (with or without huddling). Most of the activity was standing; the percentage of locomotor behaviour was about 5 % of the observations. The frequency of major behavioural states, in descending order, were: eating, resting, standing and moving.

Resting was most common at night, especially between the hours of 01:00 and 04:00, but the horses also rested in the daytime, especially between the hours of 12:00 and 14:00 (Fig. 4) (I). Resting occurred mostly inside the loose house both in the daytime and at night, but the horses also rested to some extent outdoors in the paddock and in the entrance shelter. Activity (includes standing) was most common in the morning and afternoon, starting to diminish after 14:00 and increasing again after 05:00. The horses ate hay throughout the day, but hay eating was most common in the daytime between the hours of 8:00 and 16:00, and in the evening between the hours of 18:00 and 22:00. Overall, the horses spent a total of 43 % of the observations inside the loose house, 51 % in the outdoor paddock and 5 % in the entrance shelter.

Figure 3. The 24-h time budget of the weanling horses in a loose housing system from December to March (I). The behavioural classes are mutually exclusive.
5.1.2 Distances travelled under different management conditions

Table 7 presents the distances travelled by the horses under different management conditions \((U_1)\). The yearling horses and foals at pasture in the summer travelled the longest distance per day. Average distances travelled per day were about the same in the weanling horses in the loose housing system and in the group box/paddock system in the winter. Speed was highest in the pastured yearling horses \((0.4\ km/h,\ or\ 0.11\ m/s)\). The speed was higher in the weanling horses in the group box/paddock system with a 9-h exercise opportunity \((0.3\ km/h,\ or\ 0.08\ m/s)\), than in the loose housing system with a 24-h exercise opportunity \((0.1\ km/h,\ or\ 0.03\ m/s)\).

In the summer, the horses were most active in the evenings and nights \((U_1)\). The pastured foals were most active between the hours of 16:00 and 22:00, when they travelled on average 2.3 km \((0.4\ km/h,\ or\ 0.11\ m/s)\). The pastured yearling horses were

Table 7. Distances travelled by the horses under different management conditions \((U_1)\).

<table>
<thead>
<tr>
<th>Age (n)</th>
<th>Management conditions</th>
<th>Month</th>
<th>Exercise opportunity (h/d)</th>
<th>Distance travelled per day (km) Mean</th>
<th>Min.</th>
<th>Max.</th>
<th>Speed (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foal (2)</td>
<td>Pasture</td>
<td>Aug</td>
<td>24</td>
<td>5.2</td>
<td>4.1</td>
<td>6.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Weanling (4)</td>
<td>Loose house</td>
<td>Feb / Mar</td>
<td>24</td>
<td>4.3</td>
<td>2.3</td>
<td>7.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Weanling (2)</td>
<td>Group box + paddock</td>
<td>Mar</td>
<td>9</td>
<td>3.5</td>
<td>2.1</td>
<td>4.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Yearling (2)</td>
<td>Pasture</td>
<td>Jun / Aug</td>
<td>24</td>
<td>9.0</td>
<td>5.6</td>
<td>21.5*</td>
<td>0.4</td>
</tr>
</tbody>
</table>

*Note: the horses tried to escape insect attack
most active between the hours of 22:00 and 04:00, when they travelled on average 2.9 km (0.5 km/h, or 0.14 m/s). In the winter, the horses were most active in the daytime between the hours of 10:00 and 16:00. At that time, the weanling horses in the loose housing system travelled on average 2.1 km (0.35 km/h, or 0.1 m/s), and in the group box/paddock system 2.3 km (0.4 km/h, or 0.11 m/s).

5.2 Effects of a cold housing environment on horses

5.2.1 Behaviour

Ta did not correlate with the time spent lying with huddling ($R^2=0.00$, $p=0.86$, Linear Regression) or without huddling ($R^2=0.08$, $p<0.05$).

**Figure 5.** The effects of relative humidity (RH) (a–c), precipitation (d) and wind speed (e, f) on the behaviour of the weanling horses in a loose housing system from December to March (l).
p=0.19), eating hay (R²=0.03, p=0.41) or moving (R²=0.08, p=0.19) (I). The time spent inside the loose house showed a slightly increasing trend (R²=0.16, p=0.06) and total activity a slightly decreasing trend (R²=0.16, p=0.06) with decreasing Tₐ. Instead, the behaviour of the horses correlated with RH, precipitation, wind speed and cloudiness (Fig. 5). There was a decrease in the time spent eating hay with increasing RH (R²=0.30, p<0.01) (Fig. 5a) and cloudiness (R²=0.25, p<0.05). Correspondingly, the time spent standing increased with increasing RH (R²=0.22, p<0.05) (Fig. 5b) and cloudiness (R²=0.18, p<0.05). Also the time spent inside the shelter increased with increasing RH (R²=0.17, p<0.05) (Fig. 5c), cloudiness (R²=0.20, p<0.05), precipitation (R²=0.21, p<0.05) (Fig. 5d) and wind speed (R²=0.43, p=0.01) (Fig. 5e). Increasing wind speed also increased the time spent moving (R²=0.18, p<0.05) (Fig. 5f). No signs of visible shivering were observed during study I.

5.2.2 Energy intake and growth
The average daily voluntary hay intake of the horses was 4.4±1.2 kg DM (mean±SD); it increased during the study being 3.7±1.1 kg DM in November, 4.0±0.8 kg DM in December, 4.3±0.9 kg DM in January, 4.3±0.9 kg DM in February and 5.6±1.1 kg DM in March (II). Silage was fed on average 1.6±0.4 kg DM, oats 1.0±0.2 kg DM, protein supplement 0.5±0.2 kg DM, concentrate supplement 0.09±0.0 kg DM and mineral and vitamin supplement 0.01±0.01 kg DM per day. The average forage:concentrate ratio was 80:20 (DM basis).

The ME intake of the weanling horses (75.5±11.8 MJ/d, mean±SD) was on average 30 % above the MTT (2006) requirements and SLU (2004) requirements for slow growth, and 15 % above the SLU (2004) requirements for rapid growth (see Fig. 1 in II). Tₐ increased ME intake by 0.5 % per 1 °C increase in Tₐ during the whole study period (p<0.001, LMM), but ME intake (y) varied in a non-linear fashion in the course of the winter: y = 0.086x² – 0.902x + 71.5, where x is weeks from November to March (p<0.001, R²=0.63). In early winter, ME intake increased in November by 1.8 % (p<0.001), in December by 0.5 % (p<0.001) and in January by 0.2 % (p<0.05) per 1 °C increase in Tₐ during the whole study period (p<0.001, LMM), but ME intake (y) varied in a non-linear fashion in the course of the winter. ME intake was higher, 16.1 % in November and 6.8 % in

| Table 8. Mean body weight (BW), estimated surface area, metabolizable energy (ME) intake, calculated heat production (HP), the increase in ME intake per 1 °C change in ambient temperature (Tₐ) and climatic energy demand (CED) of the weanling horses during the winter (II). |
|-----------------|---------------|---------------|---------------|---------------|
| BW (kg)         | Nov           | Dec           | Jan           | Mar           |
| Surface area (m²) | -             | 273.8         | 296.7         | 314.6         | 328.7         |
| ME intake (MJ/d) | 68.0          | 74.4          | 71.6          | 74.0          | 85.9          |
| ME intake (W/m²) | 262.5         | 238.8         | 237.3         | 267.3         |
| HP (W/m²)²      | 253.6         | 230.7         | 229.2         | 258.2         |
| ME intake (MJ/d) per 1 °C decrease or increase* in Tₐ | 1.1            | 0.3            | 0.1            | 0.4*          | 0.8*          |
| CED (W/m²) per 1 °C decrease or increase* in Tₐ | 1.0            | 0.3            | 1.2*           | 2.6*          |

* Estimated by the equation A = 1.09+0.008*BW (kg) (Hodgson et al., 1993)
2 Ratio of HP to ME 0.97 was estimated by the equation HP/ME = 1.2–0.649*ME (MJ/kg⁰.⁷⁵) (Morgan, 1996)
Results

December, at $T_a$’s below –11 °C than at $T_a$’s above –11 °C (p<0.001). Mass-specific ME intake was also higher at $T_a$’s below –11 °C than at $T_a$’s above –11 °C, about 6.3 % and 4.4 % in December and January, respectively. The calculated CED was about 1.0 W/m² in December and 0.3 W/m² in January per 1 °C decrease in $T_a$.

In late winter, total ME intake increased in February by 0.7 % and in March by 1.3 % per 1 °C increase in $T_a$ (Table 8) (II). Mass-specific ME intake increased in February by 0.3 % (p<0.01) per 1 °C increase in $T_a$ (p<0.001). In late winter, the BCS of the horses rose permanently above the target BCS (see Fig. 3 in II). The calculated CED was about 1.2 W/m² and 2.6 W/m² per 1 °C increase in $T_a$ in February and March (Table 8). The calculated rate of HP followed ME intake by the ratio 0.97.

As the feed and ME intake of the horses increased during the winter, so intakes of other nutrients such as digestible crude protein, calcium and phosphorus also increased, and hence were highest in late winter (II). Digestible crude protein intake (848±128 g/d, mean±SD) exceeded the MTT (2006) requirements (500 g/d) by about 70 % (p<0.001) and the SLU (2004) requirements for slow growth (age 3-6 months: 610 g/d; age 7-12 months: 493 g/d) by about 64 % (p<0.05) and for rapid growth (610 vs. 587 g/d) by about 44 % (p<0.05) (One-Sample t-Test). Also calcium intake (43±8 g/d) was on average 30 % above the MTT requirements (33 g/d) (p<0.05) and 39 % above the SLU requirements for slow growth (37 vs. 29 g/d) (p<0.001) and 21 % above the requirements for rapid growth (37 vs. 35 g/d) differing significantly from week 8 onwards (p<0.05). Phosphorus intake (25±5 g/d) was on average 13 % above the MTT requirements (22 g/d) (p<0.05) and 37 % above the SLU requirements for slow growth (21 vs. 17 g/d) (p<0.001) and 18 % above the requirements for rapid growth (21 g/d) (p<0.05). The magnitude of the excess intake of ME ($R^2$=0.71, p<0.001, Linear Regression), digestible crude protein ($R^2$=0.68, p<0.001) and calcium ($R^2$=0.68, p<0.001) increased with increasing voluntary hay intake (Fig. 6).

The average BW of the SB horses during the study was about the same as that presented for SB horses in Sandgren et al. (1993) (see Fig. 4a in II). The FC horses weighed about 19 % more than the FC horses in Saastamoinen and Koskinen (1993), and Ahtila and Saastamoinen (2005) (see Fig. 4b in II). The ADG of the SB horses was 0.57 kg and FC horses 0.62 kg during the study. The ADG correlated negatively with increasing $T_a$ ($y = -0.01x+0.50$, $R^2=0.15$, p<0.05, Linear Regression).
Figure 6. Excess nutrient intakes in relation to the voluntary hay intake of the weanling horses from November to March (II). ME = metabolizable energy.
5.3 Cold resistance

5.3.1 Radiative heat loss

Ta affected the rate of radiative heat loss in all the horse types except type P (Fig. 7) (III). Types L, W and C radiated more heat at 2 °C than at 15 °C (p<0.001, Mann-Whitney U). The radiative heat loss increased further at a Ta of −8 °C (p<0.05). In the weanling horses, the radiative heat loss was similar at 0 °C and −9 °C but increased significantly as Ta dropped to −16 °C (p<0.01, LMM) (IV). As Ta dropped to −23 °C, radiative heat loss declined from the

![Figure 7](image-url). The rate of radiative heat loss in the mature light (L), warmblood (W) and coldblood (C) horse types and the pony type (P) (III), and weanling horses (L + C) (IV) from the trunk (a) and neck (b) at different ambient temperatures. See text for statistics.
trunk (p<0.05).

There were no differences in the rate of radiative heat loss from the trunk or neck between the horse types at 15 °C (Fig. 7) (III). Differences started to occur at a T_a of 2 °C. Type L radiated more heat from the trunk and neck at 2 °C than types C and P (p<0.05, Mann-Whitney U), and type W radiated more heat from the neck than type C (p<0.05). At –8 °C, types L and W radiated more heat from the trunk and neck than type C (p<0.05).

5.3.2 Thermal insulation

The hair coat weight changed in all the horse types in the course of the season (Fig. 8) (III). Hair coat weight increased between August and March (p<0.001, Mann-Whitney U). In August and October, type L had less hair than the other horse types (p<0.05, Mann-Whitney U). In October, types W and C had less hair than type P (p<0.05). In March, the hair weight of types L and W was lower than that of types C and P (p<0.05). On the basis of complementary measurements, hair weight was highest in the mature horses in December (III, U_2). In the weanling horses, hair weight was highest in February (IV).

The rate of radiative heat loss from the neck decreased with the increasing hair weight of the mid-neck coat (R^2=0.12, p<0.05, Linear Regression) (Fig. 9), and the rate of radiative heat loss from the trunk increased with increasing metabolic BW (R^2=0.16, p<0.05) (Fig. 10) (IV). Hair weight (R^2=0.04, p=0.27) did not correlate with the rate of radiative heat loss from the trunk, nor metabolic BW with the rate of radiative heat loss from the neck (R^2=0.10, p=0.06). BCS had no effect on the rate of radiative heat loss from the trunk (R^2=0.004, p=0.73) or neck (R^2=0.08, p=0.10).
Results

Figure 9. Relationship between the rate of radiative heat loss ($y$) and hair weight from the neck ($x$) (IV).

Figure 10. Relationship between the rate of radiative heat loss from the trunk ($y$) and metabolic body weight ($BW$) ($x$) (IV).
6. DISCUSSION

The purpose of the present thesis was to evaluate the suitability of loose housing, which is nowadays commonly used for growing horses, for a cold, northern climate by studying the effects of a cold loose housing environment on weanling horses. Some welfare impacts, which are generally associated with different management environments and were discussed in the literature review, are summarized in Table 9. In the present thesis, the following welfare issues related to the loose housing were examined: the opportunity to fulfill behavioural needs (I), the utilization of the opportunity for free exercise (I, U₁) and the effects of a cold environment on nutrition and growth (II) and cold resistance (III, IV, U₂) (cf. Table 9). The variables used represented a variety of physiological and behavioural mechanisms described in Tables 3 and 4 in the literature review.

With regard to the applicability of the results of the present thesis, it should be noted that the loose house provided good protection from the weather elements, since it was insulated, well-bedded and had covered entrance shelters. Quite often, loose houses are uninsulated buildings without entrance shelters, and thus provide less protection from the weather than the facilities in the present thesis. Therefore, the results can be applied only to comparable loose

<table>
<thead>
<tr>
<th>Welfare-enhancing factors</th>
<th>Welfare-threatening factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stabling in single, loose boxes</strong></td>
<td><strong>Low environmental stimulation and lack of social contacts</strong></td>
</tr>
<tr>
<td>• Personal space and management routine</td>
<td>• Limited opportunity to fulfill behavioural needs: high risk of aberrant or unwanted, aggressive and stereotypic behaviour</td>
</tr>
<tr>
<td>• Low injury risk</td>
<td>• Restricted exercise opportunity: risk of retardation of growth and development</td>
</tr>
<tr>
<td>• Daily handling and control of diseases and injuries</td>
<td>• Risk of exposure to high levels of ammonia, organic dusts and mould spores</td>
</tr>
<tr>
<td>• Controlled feed intake and quality</td>
<td></td>
</tr>
<tr>
<td>• Controlled exercise</td>
<td></td>
</tr>
</tbody>
</table>

| **Group/outdoor housing** | **Social ranking order: aggressive group mates, high risk of injuries, low ranking horses may have limited access to food and shelter** |
| • Opportunity to fulfill behavioural needs | • Diseases and injuries more difficult to control |
| • Free exercise opportunity: high locomotor activity; supports normal growth and development | • Minor daily handling: restless, shy horses |
| • Social contacts | • Exposure to cold and adverse weather: increased energy need, increased risk of airway inflammations |
| • Horses are less aggressive and better to handle and train | • Feed intake difficult to control |
housing conditions. In addition, it is noteworthy that the horses used in the studies were mainly in good body condition. The effects of cold housing may be different for thin and poorly managed weanling horses, especially when housed in an uninsulated loose housing system.

6.1 Loose housing and behavioural needs

The circadian rhythm of behavioural patterns of the loose-housed weanling horses in study I corresponded for the most part with the circadian rhythm recorded for feral horses (Duncan, 1980, 1985; Boyd, 1998; Berger et al., 1999; Boyd & Bandi, 2002) the horses resting mostly at night, waking early in the morning, eating mostly in the morning and evening, and being most active in the daytime (Fig. 11). However, the feeding of silage and/or concentrates at 06:00, 10:00 and 16:00 modified the circadian rhythm of the weanling horses to some extent.

The time budget differed to some extent from that of feral yearling Camargue horses (Duncan 1980, 1985) living in southern France, where the winters are cool and humid (I). The most remarkable difference was in the time spent eating, which was

![Figure 11](image_url)

*Figure 11.* A simplified illustration of the circadian rhythm of behavioural patterns of Przewalski horses (*Equus ferus przewalski*) living under close-to-natural conditions in the summer (a) (based on Boyd, 1998, and Boyd & Bandi, 2002), and weanling horses in a loose housing system in winter (I) (b).
much lower in the loose-housed horses (36 vs. 63 % for loose-housed weanlings and feral yearlings, respectively). This was because, in contrast to feral horses in natural environments (Duncan 1980, 1985), the feeds of the weanling horses were energy-rich and easily available, and hence less time spent eating satisfied their energy needs. Consequently, the loose-housed horses (I) replaced eating time with standing, whereas feral horses (Duncan 1980, 1985) spent only a little time standing (26 vs. 6 %). The time spent on locomotor activity (5 vs. 6 %) and resting (32 vs. 25 %) was about the same, but the weanling horses rested mostly in a lying rather than a standing position (I), contrary to feral horses (Duncan, 1980, 1985) (25 vs. 9 %).

This may have been because there was a comfortable, dry lying place inside the loose house. They also rested recumbent all at the same time, which shows that low-ranking horses could also use the hall. Both of these observations signify that the weanling horses felt safe in the loose housing environment, because, for example, horses in pasture usually reduce lying time to minimum (Dallaire, 1986) and at least one horse remains standing while the others are lying down (McDonnell, 2003), which are protective mechanisms against predation. The weanling horses used the sleeping hall for resting in the daytime, too, and spent time outdoors in the evenings and nights, which is not possible for stabled horses kept in loose boxes at night and in an outdoor paddock in the day. Therefore, the results of study I are mainly in accordance with the hypothesis that the loose housing system would provide the horses’ with an opportunity to fulfil their behavioural needs, which is generally considered an important criterion for animal welfare (Bracke & Hopster, 2006).

The observation of all the horses lying recumbent at the same time (I) verifies that the sleeping hall was large enough for the number of horses. There was 9 m² space per weanling horse in the halls, which corresponds to the space requirement of a loose box for a mature horse. Since Finnish legislation (Ministry of Agriculture and Forestry, 1998) sets a minimum space requirement for weanling horses in a loose housing system of 3.6 m² per horse, the weanling horses had plenty of space. However, the adequacy of this minimum requirement cannot be evaluated on the basis of this thesis. For mature horses, on the other hand, the minimum space requirement in a loose housing system (7.2 m² per horse) was seen to be too little, since only three mature horses could be kept in the present loose housing system, giving a space of about 15 m² per horse. When there were four mature horses (about 11 m² per horse), one horse was not able to use the hall at the same time as the other horses. However, because space requirements were not a topic of the present thesis, these observations are suggestive.

Another hypothesis concerning behaviour was that the loose-housed weanling horses were expected to be quite active due to 24-h opportunity for exercise (Zeeb & Schnitzer, 1997). Contrary to this hypothesis and general assumption among horse breeders, the loose housing system did not encourage daily locomotor activity during the cold winter months (I). The GPS measurements (U1) confirmed the results of study I: the average speed of the horses in a loose housing system was 0.1 km/h (0.03 m/s), which signifies that the horses moved really slowly and stood still for most of the time, although short spurts were occasionally performed. The distance that the loose-housed weanling horses travelled per day in study U1 was about half of that of the yearling horses in pasture in the summer. In winter, locomotor activity was about the same as in feral yearling horses in winter (Duncan, 1980, 1985). However, feral
horses grazed in winter, i.e. ingested food while standing or travelling slowly (searching for food), so their eating time (63%) included locomotor activity. The loose-housed horses were not able to or did not have to graze due to ad libitum forage feeding, which may have resulted to relatively low locomotor activity. In the summer, the horses were able to graze which increased their locomotor activity in pasture. Accompanying eating, this is a kind of obligatory activity, which could not be performed by the loose-housed horses in winter.

Feral horses have been reported to reduce locomotor activity in winter compared to summer (Duncan, 1980, 1985; Berger et al., 1999; Arnold et al., 2006). Reduced activity in winter was an annual pattern which was related to decreased $T_{o}$, and hence to a reduction in endogenous HP and energy expenditure (Arnold et al., 2006). This adaptation mechanism helped feral horses to cope with the energetic challenge of winter. Although this adaptation mechanism would not exist to the same extent in domestic horses, who usually do not confront as hard an energetic challenge in winter due to feeding practices, it is possible that the rather low locomotor activity may have served the same purpose: the reduction of energy expenditure in winter. It should be pointed out, however, that the thick snow cover and only daytime access to a large paddock (6,400 m²) may partly explain the low activity in the present studies (I, $U_1$). The horses had access only to smaller paddocks (800 m²) at night. However, the reducing effect on activity of night-time access to smaller paddocks can be discarded, since in previous studies the sizes of paddocks which enhanced horse activity were 450 m² (Jørgensen & Bøe, 2007) and 1,600 m² (Johansson & Lindström, 2008).

The results signify that a loose housing system does not necessarily fulfil its ultimate purpose as an activating housing system in areas with a cold and long winter (I, $U_1$). Basically, a loose housing system gives horses an opportunity for high locomotor activity, but in practice, it does not seem to serve its purpose. Furthermore, on the basis of studies that show that a lack of exercise may retard growing horses' musculoskeletal development (Raub et al., 1989; Bell et al., 2001; van de Lest et al., 2002; Hiney et al., 2004), it can be hypothesized that if the locomotor activity is very low, the loose housing system does not necessarily bring any benefit when considering musculoskeletal development. However, further studies are required in order to find out whether the low locomotor activity of weanling horses in a loose housing system is adequate for normal musculoskeletal development.

Also ways to encourage locomotor activity have to be identified. For example, placing forages further from the loose house, ploughing snow in the paddocks in order to ease movement in the winter, locating the loose housing system in a varied and stimulating environment (e.g. trees or other vegetation in the paddocks, varying landscape, horse traffic near the loose house), paying attention to the structure and shape of the paddocks and forming diverse loose housing groups (e.g. groups in which horses vary in age and breed) might be suitable ways of activating horses. Agitation of loose-housed horses for exercise purposes must be avoided, since sudden, heavy exercise adversely affects musculoskeletal development (see van de Lest et al., 2002, 2003). However, a question remains as to whether it is even possible to increase the locomotor activity of horses in the cold, given that low locomotor activity is a normal response to cold weather (Duncan 1980, 1985; Berger et al., 1999; Arnold et al., 2006) and cold adaptation is a very deep-seated mechanism (Langlois, 1994).
The low activity level of the weanling horses also indicates that their actual need for locomotor activity was small, especially at night. This is supported by the fact that locomotor activity appeared mostly in the daytime in the loose-housed horses (I, U₁), and there was a small difference in daily distances travelled between the horses kept at night in a group box and those kept 24 h in a loose housing system (U₁). The small difference in total distances travelled may be a sign of compensatory locomotor behaviour, i.e. increased locomotor activity when being turned out for part of the day, in the horses kept in a group box during the night. Compensatory locomotor behaviour is common in stalled horses in response to exercise deprivation (Houpt et al., 2001; Chaya et al., 2006; Kurvers et al., 2006) and proves that stalled horses are able to fulfil their need for locomotor activity in the daytime. However, the fact that the average speed was lower in the loose housing system than in the group box/paddock system shows that locomotor activity is divided more equally during the day when the horses have a 24-h exercise opportunity than when the horses only have a 9-h exercise opportunity. On the other hand, the activity results of study U₁ should be considered preliminary since the number of horses involved was small.

One important purpose of the preliminary study U₁ was to evaluate the suitability of GPS technology for recording activity of horses. The same technology was used in a recent study, which measured the locomotor activity of foals kept in pastures under various management conditions (Kurvers et al., 2006). In the present study, it was possible to measure the distance that the horses travelled using GPS equipment, but the results are only indicative because of several problems with GPS recordings, which were also noted by Kurvers et al. (2006). The main problem was that a lot of observational days were lost due signal breaks with satellites, especially in the loose housing system, since the building sometimes interfered with reception of signals from the satellites. This is why this method cannot be recommended for use near buildings. Furthermore, the equipment recorded the activity of loose-housed horses only when they were outdoors in the paddock. Therefore, there were inaccuracies in the recordings of the loose-housed horses and the method should have been validated. In the pasture, the number of successful measurements was higher because there were no disturbing trees or buildings. The horses were not distracted by the GPS devices, but the activity of the horses, e.g. rolling and biting of the harnesses or capsules, occasionally damaged the equipment. Accordingly, there is apparently still a need to develop better methods for automatic activity recordings of free-ranging animals.

Conclusions

According to the hypothesis, free outdoor access and ad libitum forage feeding allowed the horses to follow the natural circadian rhythm of behavioural patterns in a loose housing system, which enhances horse welfare (I). The time budget differed more noticeably from that of feral horses, since it was greatly modified by management factors such as composition and quality of diet and access to a sheltered sleeping hall. The horses spent almost half the day in the hall mostly resting recumbent, which signifies that a sheltered, comfortable loose house building that is large enough for the number of horses is very important for the welfare of outdoor-housed horses. The results on activity did not support the hypothesis of the high locomotor activity (I, U₁). Evidently, the need for locomotor activity was low and was partly a thermoregulatory response to cold. It seems that the
opportunity to behave unrestrictedly rather than the opportunity for high locomotor activity is important for horses. Nevertheless, the amount and type of exercise sufficient to ensure normal musculoskeletal development of horses in a loose housing system, and also ways to stimulate activity, should be examined in future studies.

6.2 Effects of a cold housing environment on horses

The weanling horses did not modify their behaviour in response to decreasing $T_a$ in winter (I), which does not support the hypothesis that the horses would use behavioural adjustments to acclimatize to the cold housing environment. The horses did not change the time spent resting, eating hay or moving, which accords with the results of a study of loose-housed Icelandic horses (Mejdell & Bøe, 2005). Feral horses, in contrast, increased the time spent standing resting in response to decreasing $T_a$ and modified their time budget between seasons (Duncan, 1980, 1985). This indicates that, in study I, the winter weather was not challenging for the weanling horses, or alternatively, they had already acclimatized and adjusted their time budget to the cold housing environment to some extent before the study began. This latter explanation is supported by the fact that the horses had already been in the loose housing system for over a month before the study began. In addition, an adequate plane of nutrition and an insulated loose house building may have helped them to cope with the cold.

The low level of locomotor activity and the presence of huddling, which is classified as a thermoregulatory, comfort-seeking behavioural response to cold (McDonnell, 2003), at all measured $T_a$’s between $-20 ^\circ C$ and $0 ^\circ C$ may also support the fact that the horses had already adjusted their behaviour to the cold, although the proportion of activity did not decrease and huddling did not increase further at lower $T_a$’s (I). This would also support the hypothesis of the utilization of behavioural responses to cold. The incidence of huddling cannot be compared with other studies, because huddling has not apparently been previously studied in the horse. Another interesting thermoregulatory behaviour associated with resting, which has not obviously been studied in the horse, is the lying posture in relation to $T_a$. In other domestic ungulates, e.g. dairy calves (Gonzales-Jimenez & Blaxter, 1962; Kauppinen, 2000; Hänninen et al., 2003), lying on the side decreases at low $T_a$’s, whereas lying with the head on the flank with the legs curled under the body increases, which may be a way of lessening the impact of the cold by reducing the exposed body surface.

In contrast, precipitation, RH, wind speed and cloudiness had an effect on the behaviour of the weanling horses (I). The time spent eating hay decreased and the time spent in the shelter and standing increased with increasing RH and cloudiness, which was naturally a consequence of the increased time spent standing in the shelter on rainy days. Wind also increased use of the shelter, but also increased locomotor activity, i.e. the horses were restless on windy days. The results of study I concerning use of the shelter during rainy and windy weather are in accordance with earlier studies (Michanek & Ventorp, 1996; Mejdell & Bøe, 2005), and suggest that a shelter which protects the horses from adverse weather conditions is important for the welfare and thermoregulation of outdoor-housed horses.

Although the weanling horses did not modify the time spent eating hay as the $T_a$ decreased (I), it was hypothesized, on the basis of previous studies, that low $T_a$ would affect the energy needs of the horses. It was also expected that the horses would grow normally and maintain their BCS when the
Discussion

CED was taken into account in the feeding. Cold-housed growing horses have been reported to need 0.2 to 2 % more energy per 1 °C decrease in \( T_a \) below the LCT to maintain normal growth rate in cold (Cymbaluk et al., 1989a; Cymbaluk, 1990). The LCT of cold-housed weanling horses varies in the studies from 0 °C in Cymbaluk (1990) and Cymbaluk et al. (1989a) to –11 °C in Cymbaluk and Christison (1989a) depending on the housing system, environmental conditions and the horses’ level of acclimatization. This increase in energy need has not been taken into account in the Finnish feeding recommendations for horses (MTT, 2006), but the Swedish recommendations include guidelines for feeding horses during cold weather (SLU, 2004). According to the SLU, a young horse fed \textit{ad libitum} may need 1.4 % more maintenance energy for each 1 °C decrease in \( T_a \) below the LCT of –11 °C. In study II, the results concerning CED and growth of weanling horses in a cold housing environment are in accordance with previous studies, the SLU (2004) guideline and the hypothesis of the increasing energy need in the cold.

Weather conditions were harsh right from the beginning of studies I and II, so the ME intake of the weanling horses had to be increased above the maintenance level in order to maintain a moderate BCS and normal growth rate (II). ME intake increased by 1.8 % in November, 0.5 % (CED 1.0 W/m²) in December and 0.2 % (0.3 W/m²) in January per 1 °C decrease in \( T_a \). Accordingly, the HP of the weanling horses, as estimated from the ME intake, was relatively high, varying between 231 and 258 W/m² during the winter. For comparison, similar MR values have been recorded for neonatal foals after birth (Ousey et al., 1991), and much lower values (about 120 W/m²) in few-day-old foals at \( T_a \)’s below their LCT (Ousey et al., 1992). The LCT of the weanling horses was about –11 °C, since ME intakes were higher at \( T_a \)’s below than above –11 °C, and were approximately the same between 0 °C and –11 °C. This LCT result supports the estimation of LCT (–11 °C) by Cymbaluk and Christison (1989a) for light horse weanlings, which were kept under comparable climatic and management conditions. As in my study, Cymbaluk and Christison (1989a) also defined the LCT on the basis of feed intake, and, in both studies, the LCT was defined for animals in their natural state i.e. animals performing their normal activities (field metabolic rate, Randall et al., 2001) and with specific thermal resistance, and not in rested, fasting animals in a post-absorptive state (BMR, IUPS Thermal Commission, 2003). Although there were similarities in the horses, management conditions, climate and LCT definitions, it should still be remembered that the LCT values are not directly comparable since many other factors, e.g. BCS, body size, physiological status, MR and acclimatization, and also the quality of feeds and intensity of feeding, affect the LCT value (Cymbaluk, 1994; Morgan et al., 2007).

Low \( T_a \) increased both the total and mass-specific ME intakes of the weanling horses in early winter but not in late winter (II), which is in accordance with a previous study of cold-housed weanling horses (Cymbaluk & Christison, 1989a). A drop in \( T_a \) to –20 °C would hence increase the daily ME need by about 18 % in November, 5 % in December and 2 % in January. The decreasing CED signifies that the horses acclimatized progressively to the cold environment as the winter proceeded, and that the improving cold resistance was mainly caused by increasing body insulation. However, it is not clear whether the improved insulation was caused by increasing coat insulation or by the decreasing ratio between heat dissipating surface area and heat producing/retaining body mass as the
horses grew, or by both of these. The former is supported by study IV, where the body insulation of the weanling horses, as measured by hair weight, increased during the winter. In addition, on the basis of study I, the horses probably used behavioural thermoregulation in acclimatization. It is also possible that some other physiological mechanisms, e.g. piloerection, vasoconstriction or adjustments in respiration rate, may have occurred that were not examined in the present studies.

Overall, the results indicate that the level of acclimatization has a great effect on the CED of weanling horses in a cold environment (II). Early winter, in particular, may be nutritionally very challenging before weanling horses become cold-acclimatized. Conversely, in late winter when horses are older and well acclimatized to cold, the SLU (2004) guideline to increase energy intake by 1.4 % for each 1 °C decrease in T<sub>a</sub> below −11 °C may lead to excess weight gain if followed rigidly throughout the winter. Therefore, it is important that the amount of extra energy fed is adjusted according to the horse’s level of acclimatization, and that the feeding recommendations take account of the reducing effect of acclimatization on the extra energy need.

In contrast to the situation in early winter, the energy intake of the weanling horses increased in late winter as T<sub>a</sub> increased (II). Increasing body size (maintenance energy need increases), changes in the composition of weight gain (the protein content of gain decreases and fat content increases with age) and increasing capacity for feed intake probably explain the increased energy need (Frape, 1998; NRC, 2007) and, hence, increased voluntary forage intake in late winter. Markedly increased hay intake combined with slower growth rate and higher T<sub>a</sub> in late winter caused BCS of the horses to exceed the target score. Their nutrient intakes were also tens of percentage points above nutrient requirements, because as the feed and ME intakes increased, also intakes of other nutrients increased.

A positive correlation between voluntary hay intake and excessive nutrient intake proves that overfeeding was mainly caused by ad libitum hay feeding, and that the reduction in concentrates and silage fed was not sufficient to prevent overfeeding (II). Since it has also been previously reported that ad libitum-fed growing horses tend to have a higher nutrient intake than their nutritional needs (Cymbaluk & Christison, 1989a, 1989b; Cymbaluk et al., 1989a) and are susceptible to overfeeding and imbalanced nutrition (Cymbaluk et al., 1989a, 1989b, 1990), ad libitum forage feeding practices in loose housing systems should be reconsidered at least in late winter, especially when the quality of the forages used is good. The excellent nutritional value of the feeds probably increased the excessive intakes in the present study. In fact, the feeding of silage should have been stopped when the horses had acclimatized to the cold. Silage was originally included in the diet in order to ensure adequate nutrient intake in early winter when the horses were not cold-acclimatized, had a high growth rate and had limited capacity for feed intake. The ration of mineral and vitamin supplement could not be decreased since it was important in balancing the calcium/phosphorus ratio in the diet.

The intakes of ME, digestible crude protein, calcium and phosphorus were about 30 to 70 % above the nutrient requirements for 6-12-month-old slow growing horses, and about 15 to 45 % above the requirements for rapid growing horses (SLU, 2004; MTT, 2006) (II). Therefore, the nutrient intake of the horses was sufficient for rapid growth, their ADG and BW were the same as or higher than in horses of similar age and breed in earlier studies (Saastamoinen, 1989a, 1989b, 1990).
in a cold group housing system is complicated even under well-controlled experimental conditions. Thus, the risk of over-feeding and imbalanced nutrition is high in loose housing systems in late winter. This problem is illustrated in Fig. 12. The difficulties in regulating the nutrient intake and BCS of horses result from the changes in both the environment (fluctuating $T_a$) and the animals (changing level of acclimatization, growth rate and capacity for forage intake), and also from the group housing situation in which forage intake cannot be adjusted individually. It has been previously reported that the balancing of nutrient intakes of growing horses is already difficult for horse breeders (Gibbs & Cohen, 2001), and cold housing increases this difficulty. Therefore, the “nutritional welfare” of loose-housed weanling horses may be impaired. Extra energy needed for maintenance in early winter and excess forage intake in late winter also increase feeding costs and lower the profitability of loose

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**Figure 12.** A simplified synthesis of the fluctuation of biological and environmental variables in loose housing conditions during the winter (II). $T_a$ = ambient temperature, CED = climatic energy demand, ADG = average daily gain, BCS = body condition score.
house rearing of horses.

In addition to energy intake, the rate of radiative heat loss, as measured by infrared thermography, was also expected to increase with falling $T_a$. In mature horses, the radiative heat loss was higher in the examination conducted at 2 °C than at 15 °C, and higher in the examination at –8 °C than at 2 °C (III). In the weanling horses, radiative heat loss was similar at 0 °C and –9 °C, but increased as $T_a$ dropped to –16 °C (IV). Lower radiative heat loss from the trunk at –23 °C than –16 °C was probably caused by the frost on the surface of the hair coat at –23 °C. Thus, the hypothesis that radiative heat loss increases as $T_a$ decreases can be accepted.

Conclusions
The responses of the horses to $T_a$ are summarized in Fig. 13 (I, II, III, IV, U1). Contrary to the hypothesis, the weanling horses did not greatly change their behaviour as a response to falling $T_a$. This indicates that they probably had adjusted their behaviour, especially locomotor and resting behaviour, to prevailing conditions before studies I and II began. Precipitation, RH and wind had a great effect on behaviour, i.e. the weanling horses used behavioural responses in order to diminish the adverse effects of rainy and windy weather on heat balance (I). According to the hypothesis, radiative heat loss increased with falling $T_a$ except in type P (III, IV). Similarly, energy intake increased markedly below –11 °C signifying that the weanling horses responded to cold by increasing metabolic HP (II). Low $T_a$ did not increase the energy need in late winter, indicating that the horses acclimatized to the cold environment during the winter. Improved cold resistance was caused by increasing body insulation, as measured by hair weight (IV), and by increasing body size (II). As presented by Young (1975), horses used behavioural and metabolic thermoregulation in the cold in the short run and insulation changes in the long run.
6.3 Cold resistance of different horse types

Knowledge of the cold resistance and LCT of different types of horses is of practical use, e.g. with respect to the ventilation of stables and feeding and management practices (i.e. housing system, blanketing and clipping) in a cold climate (Morgan et al., 2007). However, the cold resistance and LCT values of different horse types have not been systematically studied. Moreover, the methods used to determine the LCT and the research designs vary greatly in existing studies (see Table 2 in the literature review), probably because the most reliable methods for measuring the MR, an animal calorimeter and respirometer (Randall et al., 2001), demand expensive equipment, particularly in the case of large animals.

In the present studies, the thermoregulatory capacity of different horse types (III) and weanling horses (IV) was evaluated using infrared thermography, in which the measurement of heat loss is based on the radiative temperature of an object (Dere- niak & Boreman, 1996). Therefore, thermography measures radiative heat loss from an object, not total heat loss, which consists of convection, conduction, radiation and evaporation (Clark & McArthur, 1994). In a thermoneutral diagram (Mount, 1973), LCT is defined on the basis of increasing non-evaporative heat loss consisting of convection, conduction and radiation. It is probable that in a standing animal in still air conditions, this increase in non-evaporative heat loss below the LCT is mainly caused by an increase in natural convection and radiation, because, in a standing animal, conduction is small and can be neglected (Clark & McArthur, 1994). Convection and radiation follow the temperature gradient
i.e. both should increase as the temperature difference between the body surface and $T_a$ increases (Langlois, 1994; Randall et al., 2001), although it has been speculated that in still air conditions, and especially in animals with an intact hair coat, convection may be of limited significance in the cold (Davenport, 1992). Therefore, it might be possible to evaluate the approximate location of this break point on the basis of radiative heat loss. Nevertheless, since total non-evaporative heat loss cannot be determined in field conditions such as in the present thesis, and the heat balance system is overall complex and dynamic (Mount, 1973), obtaining true values would require the definition of HP from oxygen consumption.

The rate of radiative heat loss differed between the horse types as measured by infrared thermography (III). Generally, radiative heat loss increased in all the horse types except type P as $T_a$ decreased. The L and W horse types also dissipated more radiative heat at low $T_a$’s than the C and P types. The differences were probably caused by inter-individual variation in body insulation, which was supported by the negative correlation of hair weight and radiative heat loss (IV). However, the BCS of the horses did not correlate with radiative heat loss, which was probably due to the small variation in the BCS values of the horses. Figure 14 illustrates the development of the winter coat in the different horse types. The figure is based on the hair weight measurements conducted at the same time as the thermographic examinations (III) complemented by hair weight measurements done later with partly the same horses ($U_2$). Hair coat density and length was highest in December except in type C, which was probably caused by the fact that the horses used for the complementary measurements were partly different from those horses whose results the figure is otherwise based on. Altogether, the development of the winter coat supports the

![Figure 14](image)

**Figure 14.** A simplified illustration of the development of the winter coat in different horse types (L = light horse type, W = warmblood horse type, C = coldblood horse type, P = pony type) (III, $U_2$).
results of the infrared thermography, because the rate of radiative heat loss was highest in horse types L and W, which had the lowest hair coat weight. The precise development and thickness of the winter coat in different horse types should be studied further with more horses, with the measurements being done during one winter.

The results for radiative heat loss and winter coat development suggest that there might be differences in cold resistance between different horse types (III). Types P and C seem to be more cold-resistant and thus better adapted to the cold than types L and W. This would be in accordance with the hypothesis and the general evolutionary theory of northern and southern horse breeds (Langlois, 1994). The evolutionary theory suggests that a spherical body form is an advantage in a cold climate, because it reduces the exposed portions of the body. Northern horse breeds are generally heavier and shorter than southern horse breeds, and have shorter extremities which are well protected by hair, mane and fetlock, whereas southern horse breeds’ extremities are longer and the coat provides less insulation. These facts support the hypothesis that loose housing might be better suited to coldblood horses and ponies. In addition, the preliminary results are in accordance with the study by Mejdell and Bøe (2005), who noted that Icelandic horses, which are thought to be hardy with regard to cold resistance, managed well in a loose housing environment with \( T_a \)’s down to \(-31^\circ C\).

In view of genetic differences in cold resistance, the loose housing of the W and L horse types may be questioned. Moreover, according to the Ministry of Agriculture and Forestry Statute on Animal Protection (396/1996), only those production animals and breeds that are adapted to outdoor housing can be reared outdoors all year round. The risk of negative welfare effects in a loose housing system may thus be higher for light and warmblood horse breeds than for coldblood and pony breeds. However, as mentioned above, for confident conclusions about cold resistance, further studies are needed regarding this issue. In addition, total body insulation, which consists of the body tissue, hair coat and air acting in series (McArthur, 1991), of different horse types should also be determined.

In the weanling horses, radiative heat loss was similar at 0 \( ^\circ C \) and \(-9^\circ C \) but increased as \( T_a \) dropped to \(-16^\circ C \) (IV). Assuming that radiative heat loss follows the heat gradient (Langlois, 1994; Randall et al., 2001), and hence increases below the LCT, the result may indicate that the LCT was probably between \(-9^\circ C \) and \(-16^\circ C \). This LCT range, as measured by infrared thermography, agrees with the LCT value of \(-11^\circ C \) defined on the basis of ME intake (II). It would also support the LCT result (\(-11^\circ C \)) of Cymbaluk and Christison (1989a) for outdoor-housed, light horse weanlings. At the time of the thermographic examinations, the weanling horses had apparently acclimatized to the cold housing environment to some extent, which is supported by the fact that their hair weight per area unit was approximately the same as in mature FC horses in winter in study III. So this LCT value can only be applied to weanling horses that have already acclimatized to the cold to some extent. In the autumn, when weanling horses are usually brought to loose housing systems, their LCT may be considerably higher.

According to the general model of the TNZ (Mount, 1973), increasing non-evaporative heat loss signifies that an animal’s body insulation is maximal and it has to increase its metabolic HP in order to maintain a constant \( T_b \). Although only radiative heat loss was measured in study IV, it can be hypothesized that convection may also have increased at very low \( T_a \)’s (\(-16^\circ C \)
and −23 °C). Therefore, the horses had to replace increasing non-evaporative heat loss by increasing metabolic HP, because they remained normothermic. This is supported by the results of study II, where the ME intake was higher at T_a’s below −11 °C than above −11 °C, and HP, as calculated from feed intake, was generally high. Apparently, on the basis of the literature (Pagan & Hintz, 1986; Morgan, 1995; Vernet et al., 1995; McDonald et al., 2002; Morgan et al., 2007), high ME intake and HP improved the cold resistance of the weanling horses (II). The weanling horses evidently thermoregulated effectively even at very low T_a’s. Hence, the present (I, II, IV) and previous studies (McBride et al., 1985; Cymbaluk & Christison, 1989a; Cymbaluk, 1990; Morgan et al., 1997; Mejdell & Bøe, 2005) suggest that the horse as a fairly well-insulated, large endothermic animal, could tolerate subzero temperatures rather well, provided that the CED is taken into account in the plane of feeding and the horse has access to a protective, well-bedded shelter. The present studies did not examine extensively the effect of rain and wind on horses, but, since horses have been generally observed to shiver visibly during poor weather (Irvine, 1967; Mejdell & Bøe, 2005), it may be that rainy and windy weather is more challenging for the horse than dry, sub-zero weather.

Conclusions

Infrared thermography is not the most suitable method for evaluating the cold resistance of different horse types since it measures radiative heat loss, not total non-evaporative heat loss, which increases below the LCT. However, since there were differences in the rate of radiative heat loss between horse types and those types with the lowest hair coat weight lost most radiative heat, it is possible that infrared thermography revealed differences in cold resistance to some extent. Further studies, where cold resistance is evaluated, e.g. on the basis of MR, are needed in order to confirm these observations. Weanling horses are fairly cold resistant, since they remained normothermic despite of increasing radiative heat loss in the cold.
7. SUMMARY AND CONCLUSIONS

The welfare of horses under different management conditions has recently become a subject of debate. Loose housing, which is an alternative housing system for stabling, is expected to solve many of the welfare-threatening factors associated generally with box stabling. This thesis examined the suitability of a loose housing system as a winter environment for horses in a cold climate. The studies focused mainly on weanling horses, but the suitability for different horse types was also considered.

Weanling horses are usually weaned from their dams just before they are brought to a loose housing system in autumn, and they originate from many different stables. Therefore, a lot of changes, such as weaning and changes in living and thermal environments, social relationships and feeding, occur in their lives during a short time interval. The time before and when arriving in a loose housing system may thus be very stressful for weanling horses. They are not acclimatized to the cold and may become ill if one of the horses is carrying, e.g. an influenza virus. Accordingly, welfare problems are most likely to occur in autumn and early winter.

However, the present thesis demonstrates that loose housing provides horses with the opportunity for more unrestricted behaviour than box stabling, which is unquestionably a welfare-enhancing factor. In addition, weanling horses are capable of acclimatizing to a cold housing environment, which signifies that they can be reared in cold loose housing systems in winter in a northern climate, provided that the level of feeding, care and housing facilities are adequate. Nevertheless, because health is an important aspect of animal welfare and was not examined in the present studies, further studies are needed to examine the health status of loose-housed horses (e.g. the incidence of gastrointestinal and respiratory disorders, leg injuries or bodily injuries such as wounds, bruises and hair loss).

In more detail, the results revealed that:
1. The time budget and circadian rhythm of the weanling horses for the most part resembled those of feral horses. Therefore, the horses had a good opportunity to fulfil their behavioural needs in the loose housing system. However, loose housing did not encourage locomotor activity, which suggests that the opportunity to behave unrestrictedly rather than the opportunity for high activity is important for horses.
2. The weanling horses used the sleeping hall for resting and as a shelter to a great extent, which is why the sheltered, insulated, well-bedded loose house was important for the welfare and thermoregulation of the outdoor-housed weanling horses.
3. The cold loose housing environment increased the energy expenditure of the weanling horses in early winter. Climatic energy demand gradually decreased as the horses acclimatized to the cold housing environment. The horses utilized behavioural and metabolic adjustments when acclimatizing in early winter, and insulation adjustments in the long run. When the climatic energy demand was taken into account in the plane of feeding, the weanling horses maintained their body condition and grew at or above expected rates.
4. Changes in both the environment and weanling horses during the winter and ad libitum forage feeding made the controlling of nutrient intakes complicated. Thus, when the weanling horses in-
creased their voluntary forage intake in late winter, while they were rather inactive and their growth rate decreased, their body condition rose above a moderate level and they were susceptible to overfeeding.

5. Since the weanling horses maintained their thermal balance even at very low ambient temperatures despite of increasing radiative heat loss, they seemed to have a high thermoregulatory capacity.

6. The results for radiative heat loss and development of the winter coat indicate that there might be differences in cold resistance between different horse types, the coldblood horses and ponies being more cold-resistant than warm-blood and light horses, and thus more suitable for loose housing.

Although a cold environment is not a physiological problem in itself for the weanling horses, the stressful early loose housing period, low level of locomotor activity and complicated adjustment of nutrient intakes suggest that it does not necessarily bring significant benefits for growth and development. In fact, in order to ensure optimal growth and development, stabling in loose or group boxes with adequate, daily turnout to paddock with age-mates might be a better alternative for weanling horses than a loose housing system, because in box stabling, cold exposure is less, feed and nutrient intakes can be controlled more efficiently and, consequently, the risk for predisposition to imbalanced nutrition is lower than in loose housing systems. Loose housing might be better suited for older, yearling horses because they have nearly reached their mature size and so are not as susceptible to the effects of low T<sub>a</sub> and ad libitum feeding. Another alternative is to regulate individually both concentrate and forage intake in loose-housed weanling horses, and to develop ways of encouraging their locomotor activity. However, limited forage feeding makes high demands on the planning and implementation of feeding and management strategies for group-housed growing horses.

Knowing that, when given the opportunity, horses tend to follow the natural circadian rhythm of behavioural patterns, it should be considered if this could also be allowed in box stabling by adjusting management practices. For example, by taking horses to outdoor paddocks early in the morning at the time when the loose-housed horses tended to wake up and leave the hall, and by taking them into the stable at the time in the evening when the loose-housed horses tended to increase time spent resting in the sleeping hall. Providing shelter from the weather during the daytime and ensuring good air quality in the stable are also essential factors to take into account. Therefore, the negative effects of stabling (listed in Table 9 above) can be efficiently prevented by good management practices.

In practical terms, it may be said that, like every housing system, loose housing also involves both welfare-enhancing and welfare-threatening factors. Therefore, the suitability of a loose housing system as a winter environment for weanling horses depends on which welfare-related factors are emphasized. In addition, it is evident that a combination of the housing facilities, management practices and the knowledge and skills of the horse keeper determines to a great extent whether loose housing is beneficial or detrimental for weanling horses. In order to ensure the welfare of loose-housed horses, current loose housing conditions and management practices should be improved through general counselling and education.
8. PRACTICAL RECOMMENDATIONS

- The need for rest is high in weanling horses. It is essential that the loose house is well-bedded and sheltered, and is large enough for the number of horses in order to enable adequate rest also for low-ranking horses.
- Insulation of the loose house and an entrance shelter are recommended, because they contribute to the heat balance of the horses by reducing the adverse effects of weather, and hence reduce climatic energy demand and feeding costs.
- Weanling horses spend a large proportion of the day eating forages and may be rather inactive. It is recommended that forage feeds be placed outside in a covered feeder in order to increase the time that horses spend outdoors. By placing forage feeding further from the loose house building, the locomotor activity of the horses may be enhanced. Other ways to activate the horses should also be considered.
- The effect of acclimatization on climatic energy demand has to be taken into account in the plane of feeding of outdoor-housed weanling horses in order to ensure normal growth rate and to avoid overfeeding and excess weight gain. ME intake should be increased by 1.8 % in November, 0.5 % in December and 0.2 % in January above the ME recommendations per 1 °C decrease in $T_a$ below the LCT, which is estimated to be $–11$ °C in loose-haired weanling horses. Existing nutrient recommendations should be modified accordingly.
- Forage feeding should be restricted in late winter if the nutritional value of forages is high, especially when the BCS of weanling horses rises above a moderate level. In that case, special attention needs to be paid to the arrangement of forage feeding in order to ensure adequate forage intake also for low-ranking horses.
- Loose house rearing is more recommendable for yearling than weanling horses since the former are not as susceptible to the effects of low $T_a$ and ad libitum forage feeding as substantially growing weanling horses.
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