Review

Thermal comfort in ruminants and equines

Version 2

Maria-Anastasia Karatzia, Domenico Vecchio, Evangelia Sossidou and Isabelle Veissier (chair)

Acknowledgements

The authors thank Luc Mounier and Deborah Temple for reviewing this document.

Review
Thermal comfort in ruminants and equines

Maria-Anastasia Karatzia[1], Domenico Vecchio[2], Evangelia Sossidou[1], Isabelle Veissier[3] (chair)

[1]Veterinary Research Institute, Ellinikos Georgikos Organismos-DIMITRA, ELGO-DIMITRA Campus, Thermi, Greece
[2]Italian National Reference Centre on Water Buffalo Farming and Productions Hygiene and Technologies (CReNBuf), Istituto Zooprofilattico Sperimentale del Mezzogiorno, Portici, Italy
[3]UMR Herbivores, University Clermont-Auvergne, INRAE, VetAgro-Sup, 63122 Saint-Genes-Champanelle, France

November 2025

This review is a publication of the European Union Reference Centre for Animal Welfare for Ruminants & Equines. EURCAW *Ruminants & Equines* was designated by the European Commission through implementing decision of 6 May 2021, in accordance with Regulation 2017/625/EU.

Disclaimer

This review can be downloaded for free at https://doi.org/10.5281/zenodo.17661637

Citation: Karatzia, M.A., Vecchio, D., Sossidou, E. & Veissier, I. (2025). *Review - Thermal comfort in ruminants and equines*. EURCAW Ruminants & Equines.

Each EURCAW *Ruminants & Equines* review provides background information on the biological relevance of the welfare topic. It then presents the most important key areas to focus on during welfare inspections, describes why welfare issues occur and lists specific animal-based indicators that can help official inspectors to identify these welfare issues. Finally, the review summarises good and better practices that can help to solve the previously described welfare issues, and deals with related legislative requirements.

EURCAW *Ruminants & Equines* produces its reviews according to internationally accepted scientific standards, which include an external peer review process. However, it cannot accept liability for any damage resulting from the use of the results of this study or the application of the advice contained in it.

info@eurcaw-ruminants-equines.eu

https://www.eurcaw-ruminants-equines.eu/

https://www.linkedin.com/company/eurcaw-ruminants-equines/

Designated by the EU Commission

Contents

1 Executive Summary

Like all animals, farm animals are adapted to a certain range of thermal conditions, often defined by air temperature and humidity. Animal management systems and geographical location within the EU typically determine the risks of exposure to heat or cold stress. In the past, heat stress was experienced by animals mainly in southern Europe and cold stress was experienced by animals mostly in northern Europe. However, during the 21st century, the temperature will reach levels corresponding at least to moderate heat stress in most European regions (Carvajal et al., 2021; Hempel et al., 2019).

Animals react to heat by decreasing feed intake, decreasing their basal metabolism (associated with reduced metabolic heat production), increasing their respiratory rate (possibly with panting), looking for shade and reducing their activity.

Animals react to cold by increasing feed intake, increasing their basal metabolism (production of glucose, fatty acids in ruminants) to generate metabolic heat, staying close to other animals, avoiding cold areas and draughts, staying more often in sunlight or in areas protected by vegetation or a shelter.

The thermoneutral zone (TNZ), that is the thermal zone in which an animal does not have to generate or lose heat to maintain its body temperature, depends on the species, the breed (e.g. dairy vs. beef breed), the age and the vigour of the animal. It ranges from -5 to 25 °C for dairy cows, 5 to 25 °C for horses, 6 to 27 °C for goats and 12 to 27 °C for ewes. Young animals are more sensitive to cold than adults.

Animals can be protected from heat by providing shade in outdoor systems and adapting the ventilation during housing while ensuring that animals have access to cool or cold water, have limited physical exercise, and, specifically for ruminants, are fed either roughage of good quality or a more concentrated diet. Spraying water can also encourage evaporation that in turn cools animals. Animals can be protected from cold when housed by reducing draughts and air humidity, providing a deep litter, adequate feeding and warm water. Supplementary heating can also be used, especially for young animals.

2 Foreword

European Union Reference Centres for Animal Welfare (EURCAWs) aim at improving the enforcement of the legislation on animal welfare, which is one of the Commission's priorities. The EURCAWs provide technical support and coordinated assistance to EU Member States in carrying out official controls in the field of animal welfare. The present review focuses on thermal comfort in ruminants and equids.

Like all animals, farm animals are adapted to a certain range of thermal conditions, often described by air temperature possibly combined with humidity. Animal management systems and geographical location within the EU typically determine the risks of exposure to heat or cold stress.

In the past, heat stress was experienced by animals mainly in southern Europe and cold stress was experienced by animals mainly in northern Europe. However, according to climatic projections, the temperature will significantly increase in the 21st century (by 1–5 °C on average each year by the end of the century) and reach levels corresponding to at least moderate heat stress in most European regions and severe heat stress in some regions (Carvajal et al., 2021; Hempel et al., 2019).

The EU legislation concerning the thermal range that farm animals must be kept in addresses only the issue of thermal stress. More specifically, EC Regulation 1/2005 for the transport of animals stipulates that it is necessary to *"protect the animals from inclement weather, extreme temperatures and adverse changes in climatic conditions"*. Again, according to Council Directive 98/58/EC that applies to all farm animals, housing conditions must avoid harm due to inappropriate thermal conditions. There is, however, a wide gap between harm due to extreme conditions and thermal comfort.

The thermal conditions that animals can adapt to vary with factors such as species, age or adaptation capacities. However, the exact range of air temperature and humidity in which animals should be kept is not specified in Council Directive 98/58/EC, nor in Directive 2008/119/EC specific to calves. EC Regulation 1/2005 stipulates that ventilation systems must be capable of *"maintaining a range of temperatures from 5 °C to 30 °C within the means of transport, for all animals, with a +/- 5 °C tolerance, depending on the outside temperature"*, leading to a range of tolerated temperatures from 0 to 35 °C.

Due to the increasing risks and the lack of clear recommendations, EURCAW *Ruminants & Equines* reviewed the knowledge available on thermal comfort in these species. In the present document, we first address how animals adapt to thermal conditions outside their thermoneutral zone, we then synthesise the information on thermal conditions that correspond to comfort and stress depending on species and age, we identify the risks in the EU, and we finally review solutions to ensure thermal comfort.

3 Definitions[1]

Accumulated heat load	AHL	An index that combines HLI and the time of exposure (Gaughan, Mader, Holt, & Lisle, 2008)
Heat load index	HLI	An index that represents the combined effects of air temperature, humidity, wind speed, and radiation (Gaughan et al., 2008)
Homeothermic animal		An animal able to keep its body temperature at approximately the same level (i.e. within certain limits) despite changes in the ambient temperature.
Lower critical temperature	LCT	The threshold of ambient temperature below which the rate of heat production of a resting homeothermic animal increases (e.g., by shivering) to maintain thermal balance
Relative humidity	RH	The amount of water vapour present in air, expressed as a percentage of the amount required for saturation at the same temperature and pressure
Temperature humidity index	THI	An index that represents the combined effects of air temperature and humidity (Hahn, Mader, & Eigenberg, 2003)
Temperature, black globe	T_g	The temperature of a black hollow sphere as measured by a thermometer at its centre. It represents the effects of ambient temperature, wind cooling and solar radiation (Li, Gebremedhin, Lee, & Collier, 2009)
Temperature, dew-point	T_{dp}	The temperature at which condensation first occurs when air is cooled at constant pressure.
Temperature, dry bulb	T_{db}	The temperature of gazes measured by a thermometer shielded from radiation
Temperature, wet bulb	T_{wb}	The lowest temperature to which a parcel of air can be cooled by evaporating water
Thermal comfort zone	TCZ	The range of environmental temperatures included in TNZ, where specific mechanisms of thermoregulation are necessary to maintain core body temperature and the animal is in the preferred or chosen thermal environment (Silanikove, 2000)
Thermogenesis		The process of heat production in the body
Thermoneutral zone	TNZ	The range of ambient temperatures within which the animal does not have to expend energy to maintain normal body temperature (Becker, Collier, & Stone, 2020)
Thermoregulation		The maintenance of temperature within certain limits despite variable internal or external heat loads
Upper critical temperature	UCT	The ambient temperature above which the rate of evaporative heat loss of a resting thermoregulating animal must be increased (e.g., by thermal tachypnea or by thermal sweating) in order to maintain thermal balance.

[1] Most definitions are from The Commission for Thermal Physiology of the International Union of Physiological Sciences (2001) except if otherwise stated

4 Adaptation to thermal conditions

Ruminants and equids are classified as homeothermic animals as they can uphold a stable internal body temperature despite fluctuations in ambient conditions within a certain range. The physiological mechanism that regulates the balance between heat acquisition and dissipation through interactions with the environment to uphold a stable body temperature, is called thermoregulation (Al-Ramamneh, 2023; Santos, Souza-Junior, Dantas, & Costa, 2021).

4.1 Adaptations to cold

Adaptation to cold refers to modifications/changes that occur to minimise the impact of low temperatures. The threshold below which a temperature corresponds to cold varies with several factors such as species or age (see Section 5 – Conditions for thermal comfort according to animal types).

In cold conditions, animals adjust their behaviour towards heat retention: they can gather in groups, restrict standing time to limit exposure to wind, avoid resting on cold areas, and stay in direct exposure to solar radiation (sunbathing), or in areas protected by vegetation or shelter (Terrien, Perret, & Aujard, 2011).

In cold conditions, thermogenesis, that is, generating heat from the body metabolism, is enhanced, namely glucose synthesis and glycolytic activity (Doubek, Slosárková, Fleischer, Malá, & Skrivánek, 2003). The metabolic changes are mediated by increased levels of cortisol (Leite, Façanha, Bermejo, Guilhermino, & Bermejo, 2021). Muscles and veins may contract, resulting in shivering and vasoconstriction that respectively produce heat and limit heat loss, and the heart rate increases (Lima et al., 2022). These responses are mediated by the sympathetic nervous system. In ruminants, increased feed intake also boosts the production of heat through ruminal digestion. Exposure to cold can make animals, especially young animals, more sensitive to health disorders. In cold conditions, young animals are more sensitive to respiratory and intestinal infections (diarrhoea), their growth can be impaired, and their mortality can increase (calves: Hyde, Green, Hudson, & Down, 2022; F. L. M. Silva & Bittar, 2019) (lambs: Guo et al., 2021; Masters et al., 2023). For instance, calves exposed to cold stress are at a greater risk of developing bovine respiratory disease (BRD) (Roland, Drillich, Klein-Jöbstl, & Iwersen, 2016).

When environmental conditions become too cold for the adaptive mechanisms of an animal to be able to remain within the thermoneutral zone (**TNZ**), body core temperature, heart rate and respiratory rate drop; in extreme cases this can lead to death. In ruminants facing long-term cold conditions the production of volatile fatty acids (**VFA**) in the rumen decreases significantly, resulting in a decrease in apparent feed digestibility (Rashamol et al., 2018).

Continuous exposure of an animal population (a species or a breed) to cold conditions can result in the selection of animals that are genetically more adapted to such conditions (Berihulay, Abied, He, Jiang, & Ma, 2019). Morphological adaptations to cold stress include the development of compact-framed bodies that provide a reduced skin surface, and thick fleece that covers a

significant extent of the body and its layers repel moisture and augment heat preservation (F. L. M. Silva & Bittar, 2019; Wang, Li, Peng, & Niu, 2023).

4.2 Adaptations to heat

Adaptation to heat refers to modifications/changes that occur to minimise the impact of high temperatures. The threshold above which a temperature corresponds to heat varies with several factors such as species or age (see Section 5– Conditions for thermal comfort according to animal types).

In hot conditions, animals usually drink more, reduce their activity (they are unwilling to move and decrease feed intake), stay standing rather than lying, and seek shade, while respiration rate increases and panting may occur, i.e. the animal takes short and quick breaths (Kumar, Singh, Sahoo, & Naqvi, 2014; Ratnakaran et al., 2016). Reduced activity limits thermogenesis, while shade protects against solar radiation and panting increases evaporation (see below section 7.1 Protection against heat).

In hot conditions, the basal metabolism is reduced, mediated by alteration of hormonal secretion such as a reduction in thyroid and growth hormone production (Salama et al., 2014). As feed intake is reduced, energy balance drops. It results in reduced performance in terms of milk yield, reproductive efficiency and growth, in high-producing animals in particular (Lima et al., 2022). At the same time, cortisol is released, probably due to psychological stress (Salama et al., 2014).

Converting water from the body into vapour helps to reduce heat load (evaporative thermolysis). Respiratory frequency thus increases in hot conditions, possibly combined with panting, open-mouth breathing and hypersalivation, and sweating (Mascarenhas et al., 2023; Olsson, 2005) When panting, the inhaled air cools the veins passing around arteries at the base of the brain and so, brain temperature remains lower than the rectal temperature. Panting is generally considered to be less effective than sweating in ruminants (Olsson, 2005; Silanikove, 2000). Sweating ceases at the onset of dehydration, but can still cause electrolyte imbalance (Olsson, 2005). Sweating is more marked in equids – especially horses – than ruminants. In Zebu cattle sweat glands are larger, thus sweating is more effective than in temperate cattle breeds (Hansen, 2004).

An added stressor which animals under hot conditions have to cope with, is water scarcity. Indeed, hot environmental conditions favour the evaporation of shallow ground water reserves, which are often the main source of water for grazing ruminants. Water deprivation can elicit complex, non-specific responses that are detrimental to animal's health and productivity and is even connected to increased morbidity and mortality (El Mahdy, Boaru, Popescu, & Borda, 2016; Veerasamy Sejian et al., 2021). Small ruminants in semi-extensive and extensive systems are more likely exposed to such a deprivation than other ruminants or equines. Despite their small body size and a lower absolute requirement for water in comparison to cattle, small ruminants suffer when clean and cool water is not provided regularly. If they do not drink enough water, heat dissipation fails and milk secretion cannot be maintained (Veerasamy Sejian et al., 2021). When water becomes scarce, its quality and safety can also deteriorate with increased salinity, and increased concentration of minerals, manure, microorganisms, chemicals or algae contamination. Salinity,

in particular, is considered a basic water quality parameter which effects palatability of feed, performance and, in the long run, health status of ruminants (Umar et al., 2014).

Body core temperature rises when the adaptive mechanisms are not sufficient to cope with hot conditions; in extreme cases this can lead to death. In camels, however, maintaining body core temperature does not seem to be the priority, rather an elevation of body temperature to 41–42 °C is observed in case of hot ambient conditions (Hussen, 2021).

As for exposure to cold, some animals may be morphologically more adapted to hot conditions due to their coat and skin colour, fleece texture, body shape/size and even adipose tissue deposition (Shaji, Niyas, Chaidanya, Sejian, & Bhatta, 2015). For instance, light coat colour is associated with better adaptation towards hot conditions. However, this is not the case in camels, for which coat colour does not influence heat tolerance (Alhaidary, Samara, Okab, & Abdoun, 2013). In addition, bigger and taller animals can dissipate heat quickly and effectively, while being able to store and use body fat when feed is scarce due to high temperatures (McManus et al., 2022). Some breeds of small ruminants originating from warm climates, such as Assaf or Manchega sheep, seem more adapted to heat: they maintain a better level of production and have a slower rate of decline of production as temperatures rise. Similarly in cattle, *Bos taurus indicus* (Zebus) suffer less from heat than *Bos taurus taurus* (Beatty et al., 2006; Elayadeth-Meethal & Kolathingal-Thodika, 2025). However, the genes associated with desired features, such as positive growth rate and persistent milk production in hot climatic conditions, are often characterised by low heritability (Carabaño et al., 2017).

5 Conditions for thermal comfort according to animal types

5.1 Concepts and indices

5.1.1 Thermoneutrality and thermoneutral zone

Thermal neutrality (or thermoneutrality) has been defined as the metabolic state of an organism in an environmental temperature at which it does not have to generate or lose heat (Gordon 2012). In the case when there is no need for an organism to exchange heat energy with its environment, i.e. no need for gaining or losing heat energy, this organism is in thermal neutrality.

The thermoneutral zone (**TNZ**) is defined as the range of ambient temperatures within which the animal does not have to expend energy to maintain body temperature (Becker, Collier, & Stone, 2020). In TNZ, "*temperature regulation is achieved only by control of sensible (dry) heat loss, i.e. without regulatory changes in metabolic heat production or evaporative heat loss*" (The Commission for Thermal Physiology of the International Union of Physiological Sciences (IUPS Thermal Commission), 2001). The lower critical ambient temperature point (**LCT**) and the upper critical ambient temperature point (**UCT**) indicate the limits of TNZ. When animals experience conditions beyond LCT and UCT, thermoregulatory mechanisms are activated to keep body temperature stable (Patel, Rajput, & Bariya, 2016; V. Sejian, Bhatta, Gaughan, Dunshea, & Lacetera, 2018). LCT corresponds to the ambient temperature below which the rate of heat conservation or production of a resting homeothermic animal increases to maintain thermal

balance (Figure 1), e.g. through vasoconstriction, piloerection, and heat production via increased metabolism from shivering. UCT corresponds to the ambient temperature above which an animal must increase the use of physiological mechanisms to prevent a rise in body temperature above normal (e.g. through vasodilation, sweating, open mouth breathing).

Beyond certain thresholds (lower than LCT or higher than UCT), thermoregulatory mechanisms are no longer sufficient to maintain body temperature. Hyperthermia vs. hypothermia may then occur, with subsequent disruption of physiological functions (Foroushani & Amon, 2022). In temperate countries in Europe, animals should be kept above LCT in winter and below UCT in summer.

5.1.2 Thermal comfort zone

Based on studies in humans (e.g. Kingma, Frijns, Schellen, & Van Marken Lichtenbelt, 2014; Schlader, Simmons, Stannard, & Mündel, 2011), the thermal comfort zone (**TCZ**) is defined in terms of perception. TCZ is the zone included in TNZ where no specific mechanisms are needed to maintain core body temperature and the animal is in its preferred or chosen thermal environment (Silanikove, 2000). Therefore, TCZ is the most suitable concept to describe the relation between an animal and its environment from the viewpoint of animal welfare. The lower limit of TCZ, is the threshold where an animal will activate vasoconstriction, piloerection and behavioural changes to maintain normal body temperature. The upper limit of the TCZ is the threshold where an animal will activate vasodilatation, evaporative physiological thermoregulation (e.g. sweating) processes to maintain normal body temperature, and may start to display thermoregulatory behaviour like increased water intake. The TCZ is sometimes called the safe zone as in EFSA Scientific Opinion on the welfare of animals in containers during transport (EFSA Panel on Animal Health and Welfare et al., 2022).

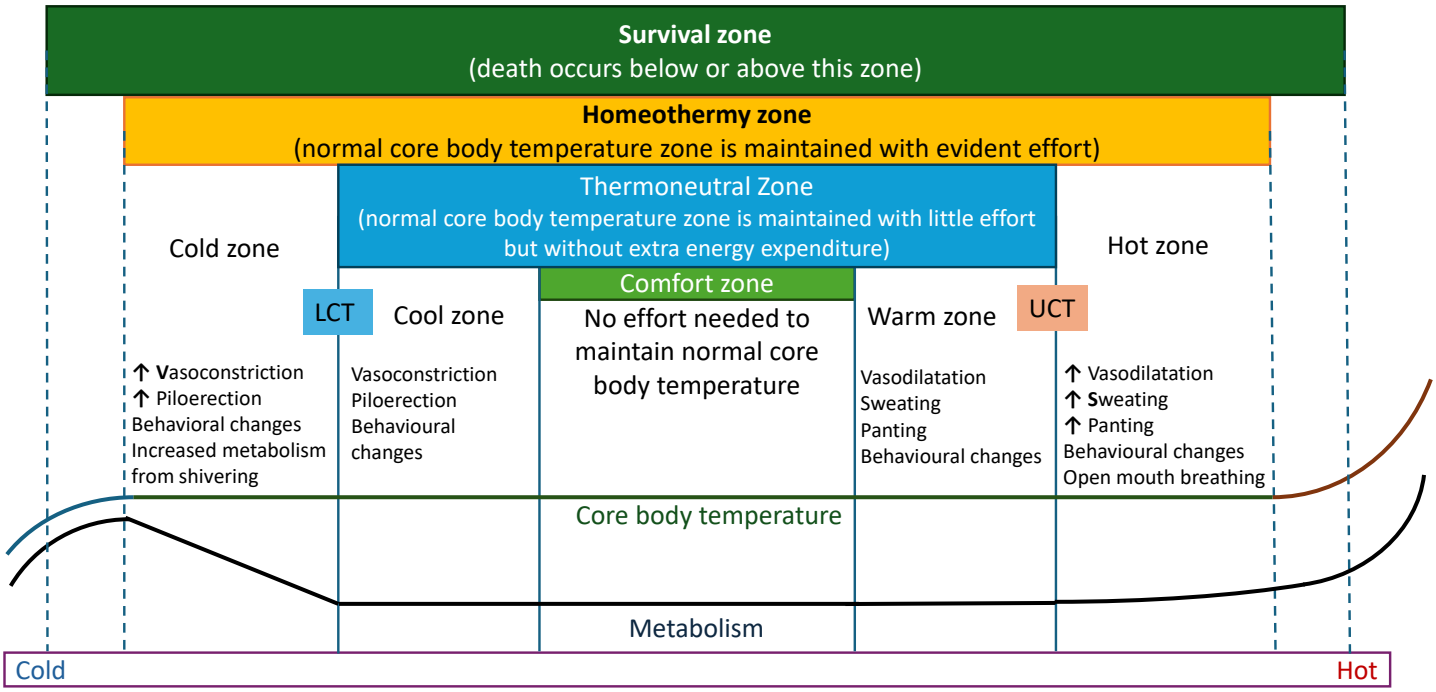

Figure 1: Thermal zones as a function of the environmental temperature. Relationship between the animal's body core temperature, heat production and environmental temperature (adapted from Silanikove & Koluman, 2015). LCT, lower critical temperature; UCT, upper critical temperature.

Thermal comfort results from a combination of ambient temperature with other parameters such as air humidity, wind speed, and solar radiation. Therefore, indices combining these parameters have been proposed (See below).

5.1.3 The temperature humidity index

To study heat stress in livestock, the temperature humidity index (**THI**) is a commonly used bioclimatic index (Hahn et al., 2003). THI represents the combined effects of air temperature and humidity. It is often used to evaluate the degree of heat stress in dairy cattle (Armstrong, 1994; National Oceanic and Atmospheric Administration, 1976). Several formulas for calculating THI have been proposed. Formulas with larger weights on humidity (vs. on temperature) better describe ambient conditions in humid climates whereas formulas with larger weights on temperature (vs. humidity) better describe ambient conditions in dry climates. Nevertheless, the most common formula is the one proposed by the National Research Council (1971):

Formula 1 $THI = 1.8T_{db} + 32 - (0.55–0.0055RH) \times (1.8T_{db} - 26)$

This formula can also be written as (Mader, Davis, & Brown-Brandl, 2006) :

Formula 1 $THI = 0.8T_{db} + (RH/100)(T_{db} - 14.4) + 46.4$

In this review we will also use the formula below proposed for Buffaloes (Yousef, 1985):

Formula 2 $THI = T_{db} + (0.36T_{dp}) + 41.2$

With T_{db}, dry bulb air temperature (measured by a thermometer freely exposed to the air but shielded from radiation) (°C); RH, relative humidity (%); T_{dp}, dew-point temperature (°C).

5.1.4 The heat load Index

The heat load index **(HLI)** was developed to include solar radiation and wind speed, especially for animals living outdoors. It is calculated as (Gaughan et al., 2008):

Formula 3 $\text{if } T_g \geq 25,\ HLI_{Tg\geq 25} = 8.62 + (0.38RH) + (1.55T_g) - (0.5WS) + e^{(2.4-WS)}$

Formula 4 $\text{if } T_g < 25,\ HLI_{Tg<25} = 10.66 + (0.28RH) + (1.3T_g) - WS$

with T_g, Black globe temperature (measured by a thermometer at the centre of a black globe) (°C); RH, relative humidity (%); WS, wind speed (m/s)

When calculated as such, HLI increases tremendously at $T_g = 25$. A correction was further introduced to obtain a smooth increase of HLI with T_g. The new calculations are as follows (Kalestone environmental, 2011):

- Whatever T_g, $HLI_{Tg\geq 25}$ and $HLI_{Tg<25}$ are calculated according to Formulas 3 and 4
- A smoothing factor **S** is then calculated

Formula 5 $S = 1/(1+e^{-(Tg-25)/2.25})$

- Then HLI is calculated as

Formula 6 $HLI = (S \times HLI_{Tg \geq 25}) + ((1 - S) \times HLI_{Tg<25})$

5.1.5 Accumulated heat load

The duration of exposure to high temperatures is of prime importance to determine the impact on animals. A high THI or HLI experienced for a short period may have the same impacts as a moderate THI or HLI experienced for a long time. Therefore, an accumulated heat load (AHL) index has been proposed (Gaughan et al., 2008):

Formula 7 $AHL = \sum_{i=1}^{n} \Delta t \times (HLI_i - HLI_{threshold})$

with Δt, the time interval of measurement of HLI (hours); n, the number of consecutive intervals for which an animal is exposed to conditions above its threshold; HLI_i, the actual HLI during interval i; $HLI_{threshold}$, the HLI when animals start panting.

$HLI_{threshold}$ depends on species, genotype, coat colour, etc. It is identified as the HLI when 20% of animals pant.

AHL below 1 corresponds to thermoneutral conditions, AHL between 1 and 10 corresponds to warm conditions, AHL between 20.1 and 50 corresponds to hot conditions and AHL above 50 corresponds to very hot conditions.

Although complex indices considering at least humidity have been proposed, most available data to define TNZ concerns temperature only. TNZ differs between species and varies according to breed, age, physiological state, health conditions, previous state of temperature acclimatisation, production, housing conditions, tissue (fat, skin) insulation and external (coat) insulation, and the behaviour of the animal (e.g. Kolacz, 2006 for sheep; Parish et al., 2016 for beef heifers). Young animals are especially sensitive to cold or heat, e.g. below LCT, calf growth is impaired and their morbidity and mortality increases (reviewed by Roland et al., 2016). In the following sections, the TNZ will be discussed for ruminant and equine species based on ambient temperature and when available on THI. Only general trends for each species will be provided.

5.2 Thermal range per species

5.2.1 Cattle

The thermal comfort zone of dairy cows typically ranges between 0 °C and 20 °C (Desrousseaux, 2021). In lactating dairy cows from European breeds, TNZ ranges between -5 and 25 °C. These values can vary between cows. The UCT and LCT of dairy cattle changes with body size, age, and level of production (Collier, Doelger, Head, Thatcher, & Wilcox, 1982). LCT in dry cows and cows at peak of lactation are -14 and -25 °C respectively, while for heifers up to 200 kg of body weight the value lies at -5 °C (Collier, Baumgard, Zimbelman, & Xiao, 2019; Young, 1981). With an increase in milk yield from 35 to 45 kg/d, UCT may decrease by 5 °C (Berman, 2005), meaning that cows will become heat stressed at a lower temperature. Cows in tropical, subtropical, and Mediterranean climates are more tolerant to heat than cows in temperate regions (Beede & Collier,

1986; Hammami, Bormann, M'hamdi, Montaldo, & Gengler, 2013; Schüller, Burfeind, & Heuwieser, 2014). Nevertheless, they may experience extended periods of heat stress and are therefore unable to recover from the negative effects of heat stress as quickly as cows in temperate climates.

THI of 72 (Formula 1) is considered the threshold value for the onset of heat stress in dairy cows. Beyond THI 72, the amount of milk produced, motor activity, dry matter intake and water intake begin to decrease, and hypersalivation, panting and tachypnoea occur (Gantner, Mijic, Kuterovac, Solic, & Gantner, 2011; Polsky & von Keyserlingk, 2017). In high-yielding cows (more than 35 kg milk/day), the THI threshold can drop to 68 (Rensis & Scaramuzzi, 2003). At THI values of 72–78, moderate heat stress begins to affect the cows, with a slight reduction in fertility and milk production. THI values between 78–82 translate into intense heat stress with a large reduction in fertility rate and milk production. With THI values exceeding 82, cow survival is in danger (Broucek, 2009; T. M. Brown-Brandl, Nienaber, Eigenberg, Hahn, & Freetly, 2003).

In beef cattle, heat stress sets in at THI values above 75 (Hahn, 1999). Beef cattle are less sensitive to heat stress than dairy cows because of their low or absence of milk production, and genetic characteristics (Ravagnolo, Misztal, & Hoogenboom, 2000). Expressed in HLI, beef cattle are in their comfort zone when HLI is below 70, they experience moderate stress between HLI 70 and 77, severe stress between HLI 77 and 85 and they are in danger above HLI 85 (Gaughan et al., 2008).

The optimal temperatures for a calf in good body condition range between 16 °C and 22 °C. The maximum recommended temperature is 25 °C and the minimum is 14 °C (EFSA Panel on Animal Health and Welfare et al., 2006). However, these values depend on housing (e.g. flooring and bedding (LCT is 18 °C when lying on concrete but 6 °C when lying on deep dry straw), presence of draughts), management (e.g. feeding level), and the age of the calf. By one week of age, calves can start to shiver at 8 °C if exposed to draughts (Webster, 1984), even if their coat is dry and they are properly fed. However, if they are fed with the aim of satisfying only a minimum maintenance level, shivering begins at 12 °C. If the coat is wet and the animals are exposed to draughts, shivering begins at 13 °C, when they are adequately nourished, and at 19 °C in poorly nourished calves (EFSA Panel on Animal Health and Animal Welfare (AHAW) et al., 2023; EFSA Panel on Animal Health and Welfare et al., 2006).

5.2.2 Sheep

On average, TNZ of adult sheep is between 12 °C and 27 °C (Marai, El-Darawany, Fadiel, & Abdel-Hafez, 2007; V. Sejian et al., 2017). TNZ however varies with breed, condition, and coat. Hair sheep (not present in Europe) cope better with heat than wool sheep (most common breeds) and their tolerance of wool sheep to heat and cold depends on whether they are shorn. UCT reaches 30 °C in hair sheep (Neves et al., 2009). In wool sheep, the UCT of shorn animals reaches 29 °C when humidity is above 80% and 32 °C when humidity is below 80% whereas the UCT of fully fleeced sheep is only 25 °C when humidity is above 80% and 28 °C when humidity is below 80%.

Similarly, the LCT of shorn sheep is only 10 °C whereas the LCT of fully fleeced wool sheep reaches 0 °C (EFSA Panel on Animal Health and Welfare et al., 2021).

For lambs, TNZ seems to range between 14 and 21 °C (EFSA Panel on Animal Health and Welfare et al., 2021).

5.2.3 Goats

Information on optimal thermal conditions for goats is scarce. TNZ seems to be between 6 °C and 27 °C (TCZ, between 10 and 18 °C), with relative humidity ranging from 60 to 80% and wind speed of 0.5 m/s (Toussaint, 1997).

5.2.4 Buffalo

For buffaloes, TCZ is between 13 and 18°C in combination with relative humidity around 55–65% and wind velocity of 5–8 km/h. As TNZ is concerned, LCT is not defined and UCT is set at 25°C (Payne & Williamson, 1990). High environmental temperature coupled with high humidity is highly detrimental to buffaloes' growth, reproduction, and production (Marai & Haeeb, 2010). THI (calculated according to Formula 2) below 72, between 72 and 80, between 80 and 85 and beyond 85 correspond to no stress, mild stress, severe stress and lethal stress (Akyuz, Boyaci, & Cayli, 2010; Kohli, Atheya, & Thapliyal, 2014).

5.2.5 Cervids

Cervids are well adapted to cold, with LCT at – 28 °C for adult reindeer and – 23 °C for their calves. By contrast, they are not well adapted to heat, with UCT of + 15 °C in adult reindeer and + 20 °C in their calves (Soppela, Nieminen, & Timisjàrvi, 1986). In red deer, adult females suffer from heat at THI above 60 (e.g. air temperature 16 °C; relative humidity 60 %) and calf growth is impaired when THI is above 72 (e.g. air temperature 25 °C; relative humidity 60 %) (Pérez-Barbería et al., 2020).

5.2.6 Camelids

For dromedary camels, TNZ seems to be between 10 and 40 °C in dry conditions (Samara & Alhaidary, 2014). However, differences may exist between breeds, age, hydration status, body condition, and sex (Alhaidary et al., 2013). Finally, it should be considered that these temperatures and those of TNZ indicated by Samara and Al-Haidary were obtained at low relative humidity values (Samara & Alhaidary, 2014).

A THI calculated (according to Formula 1) below 71 (e.g. 24 °C with 50 % of relative humidity) corresponds to no stress. At THI above 71, the core body temperature and the skin temperature increase exponentially (Habte et al., 2021). A core body temperature increasing up to 38 °C at 3 PM in the dry season suggests that camels at THI 77 (31 °C with 34 % of relative humidity) fall outside the TCZ, probably approaching UCT. However, even during the hot and dry season camels did not show significant decreases in milk production, suggesting that they do not experience severe heat stress at 38 °C (Habte et al., 2021). However, a THI of 81 or more (40 °C with 6.9 % of relative humidity) leads to a change in blood metabolites and haematological indices,

suggesting that the camels experience severe heat stress (Abdoun, Samara, Okab, & Al-Haidary, 2012).

5.2.7 Equids

For horses, TNZ ranges from 5 °C to 25 °C (Morgan, 1998). According to the commencement of evaporative heat loss and sweating, the upper threshold of TCZ is around 20 °C (EFSA Panel on Animal Health and Welfare et al., 2022).

The Federation Equestre Internationale uses WBGT to take into account thermal comfort during competitions. A WBGT above 28 °C requires precautions to reduce thermal stress, e.g. by using misting fans, and WBGT above 33 °C is not compatible with competition (Jeffcott, 1996; D. Marlin & Williams, 2018; D. J. Marlin, Misheff, & Whitehead, 2018; Schroter, Marlin, & Jeffcott, 1996).

6 Thermal ranges in European countries

Since the 1980s, climatic temperatures have shown long-term warming trends. Europe is the fastest warming continent; since the 1980s, warming in the continent has been about double the global rate (European Environment Agency, 2024). The global average annual temperature in 2023 exceeded pre-industrial levels by 1.5 °C, it also exceeded levels between 1991–2020 average across most of Europe, with a 1.02–1.12 °C increase on average (Copernicus Climate Change Service (C3S), 2024). The largest anomalies were in eastern and central Europe, with up to 2.6 °C increase in parts of eastern Europe and 2.3 °C in parts of the Alps (compared to 1991-2020). By contrast, in Scandinavia and Iceland, temperatures dropped by 1 °C below average in 2023.

Europe also faces increasingly severe climate risks, including prolonged heatwaves and droughts, heavy rainfall causing pluvial and riverine flooding, and rising sea levels causing coastal flooding (Copernicus Climate Change Service (C3S), 2024). The climate risks differ between European regions (Table 1).

Across Europe, there is an increasing number of hot days and a decreasing number of cold days. In 2022 a record number of very severe heat stress days occurred (temperatures between 38 and 46 °C), 2023 saw a record number of extreme heat stress days (temperatures above 46 °C) (Copernicus Climate Change Service (C3S), 2024), where the distinction between severe, very severe and extreme heat stress is related to human thermal comfort (according to the Universal Thermal Climate Index (UTCI), Bröde et al., 2012). In 2023, all of Europe, apart from the Nordic region and Ireland, experienced at least a few days of severe heat stress (temperatures between 32 and 38 °C), with up to 60–80 days of severe heat stress in parts of southern Europe. Much of southern Europe also experienced several days of very severe heat stress, with up to 80 days recorded in southern Spain. Parts of southern and eastern Spain, south-western France, south-eastern Italy, southern Sardinia, Greece and western Turkey experienced up to 10 days of extreme heat stress (Copernicus Climate Change Service (C3S), 2024).

Heatwaves correspond to exceptional circumstances. There is no internationally agreed definition of a heatwave. According to the European State of the Climate 2023 (Copernicus Climate Change Service (C3S), 2024), a heatwave is a period of at least three days with the daily air temperature minima and maxima exceeding the highest 5 % of values for that day during 1991–2020. According to the European Climate Adaptation Platform (Climate-ADAPT), a heatwave is a period of at least three days with the daily air temperature maxima exceeding the 99th percentile of the May to September season during a reference period. Heatwaves are getting more frequent in Europe (Baldi, Dalu, Maracchi, Pasqui, & Cesarone, 2006; Zampieri et al., 2016). The Mediterranean area is a climate change hot spot as it stands out as one of the most critical areas for heatwaves (Efthymiadis, Goodess, & Jones, 2011; Giorgi, 2006; Giorgi & Lionello, 2008; Ulbrich et al., 2012). This specific climate signal has become more evident in the second half of the 20th century and this trend is very likely to continue.

Table 1: Trends in climatic risks in Europe according to region (adapted from European Environment Agency EEA, report 01/2024; The low scenario corresponds to SSP1-2 and the high scenario to SSP3-7 from the 6th GIEC report.

Region	North[1]		West[2]		Center-East[3]		South[4]	
Scenario	Low	High	Low	High	Low	High	Low	High
Mean temperature	+	+	+	+	+	+	+	+
Heatwave days[5]	+	+	+	+	+	+	+	+
Total precipitation	(+)	+	?	(-)	(+)	?	(-)	-
Heavy precipitation	(+)	+	(+)	+	(+)	+	(+)	+
Drought	(-)	-	?	+	?	+	+	+

[1]Ireland, Norway, Sweden, Finland, Denmark, Estonia, Latvia, Lithuania
[2]France, Belgium, Netherlands, Germany, Switzerland, Austria
[3]Poland, Czech Republic, Slovakia, Hungary, Romania, Bulgaria
[4]Portugal, Spain, Italy, Slovenia, Croatia, Bosnia, Montenegro, Kosovo, Serbia, Macedonia, Greece, Turkey
[5]Days with a maximum temperature > 35 °C
+, increase; -, decrease; (), limited agreement between models; ?, low confidence in direction of change

7 How to ensure thermal comfort

When the ambient environmental conditions and the animal differ in their temperature, thermal energy is exchanged between them in the form of sensible energy exchanges, by thermal radiation, convection or conduction, or latent energy exchanges (Hoff, 2013). Thermal radiation corresponds to heat transfer by electromagnetic waves; either from the sun or surfaces of the environment not necessarily in contact with the animal. Conduction results from physical contact (direct molecular collision) with the environment. Convection corresponds to internal movements of a fluid (air, water, …), involving the transport of the properties of the fluid's particles as it moves. The difference in temperature between an animal and a surrounding fluid can induce convection which in turn increases exchanges by conduction between an animal and its environment. This process is sometimes mistakenly referred to as convection. Latent exchanges

result from liquid-to-vapour changes called evaporation, a process that consumes energy. Maintaining the animal within its TNZ can be achieved through animal management (to increase or reduce its production of heat) or acting on the environment to optimise radiation, conduction, convection or evaporation (Figure 2).

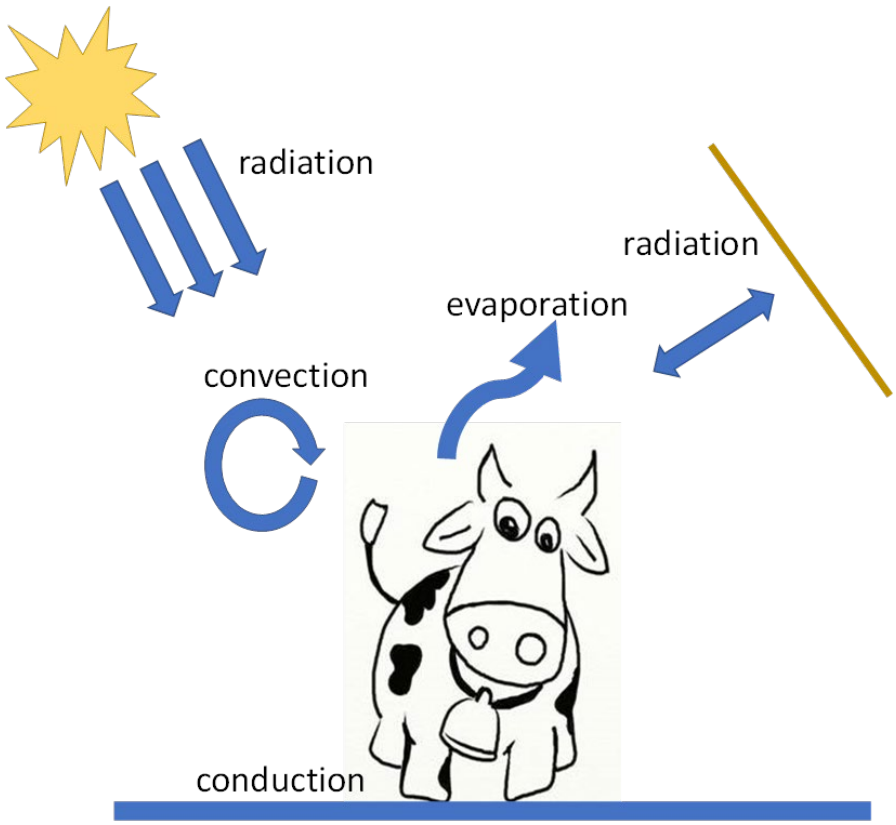

Figure 2: Heat exchanges between the animal and the environment. Note that conduction happens not only via contact with the ground but also via the contact of any part of the body and the surrounding and can be increased by convection (especially of the air).

7.1 Protection against heat

7.1.1 Limiting the production of heat by the animal

Feeding contributes largely to the production of metabolic heat by the animal. Mitigation strategies include moving feed distribution to the coolest periods of the day (end of afternoon and night) and by reducing the amount of carbohydrates, especially forage (reviewed by Brown-Brandl, 2013). In ruminants, more concentrates and more lipids can be incorporated to the diet (Yasothai, 2014).

Access to water is essential during hot ambiant conditions. Drinking cool water helps to dissipate body heat (reviewed by Brown-Brandl, 2013). Having access to water at 24–28 °C rather than 38–44 °C helps sheep maintain their feed intake and body weight in case of hot weather (De et al., 2020). Also, the need for water is increased due to evaporation of water from the skin (see below). Dairy cows drink more in the case of hot weather, e.g. 1.2 L more per 1 °C increase (Murphy, Davis, & McCoy, 1983).

The presence of other animals increases the exchange of heat. Therefore, high stocking density and overcrowding increase the risk of heat stress during high ambient temperatures. Animals should have a large space allowance when they are housed indoors or shade when outdoors. Sheep nevertheless often gather in the same place (usually shaded or with some air draught) in the case of heat, they lower their head presumably to benefit from the shade made by other animals.

Muscle activity also produces heat. Typically, body temperature rises during physical exercise and may require a few hours to return to initial levels; e.g. body temperature can increase from 38 °C to nearly 41 °C in cattle handled and restrained in a squeeze chute (T.M. Brown-Brandl, 2013). It is thus recommended not to handle, move or transport animals during high ambient temperatures. Similarly, working animals should also not work during such conditions (Sossidou, Termatzidou, Marinou, Cerasoli, & Collins, 2024). Modifying milking times for dairy animals should also be considered, e.g. milking early in the morning and late at night to avoid moving animals during hot times of the day.

In hot conditions, ruminants kept outdoors on extensively managed pastures should receive special attention. In hot conditions, pasture forage may be scarce and of low quality (fibrous) which increases the production of metabolic heat. Animals will then suffer from both heat and undernutrition. In addition, they may have to walk more to find their food or to find water, increasing heat load due to physical exercise. In hot conditions, animals kept outdoors at pasture may thus need to be supplemented with protein and fat to adequately meet their nutritional needs while limiting heat production (Silanikove 2000), access to water needs to be facilitated (to prevent animals from walking long distances), and shade must be available (see below).

7.1.2 Reducing heat load from the environment

7.1.2.1 Limiting radiation

Shade reduces exposure to solar radiation. In the case of hot weather, animals look for shade and this lowers their body temperature (Edwards-Callaway et al., 2020; Veissier et al., 2018). Shade can be provided outdoors with trees or artificial shelters, or a combination of both, e.g. cloth stretched between trees (Veissier *et al*., 2018). When shade is provided with a shelter, it is essential that the roof of the shelter is high enough or insulated to reduce radiation from the roof and allow air circulation, and the shelter should be oriented so as to benefit from prevailing wind (Nienaber & LeRoy Hahn, 2004; Shoshani & Hetzroni, 2013).

Cool roof designs have primarily been developed for humans to optimise the reflection of solar radiation. They are typically covered with white materials. Such cool roofs are efficient at reducing the temperature inside barns (by at least 3 °C) and the impact of hot weather on animals (e.g. limiting the reduction in milk production) (Santunione, Libbra, & Muscio, 2017).

Solar panels are becoming popular as a means to provide shade at pasture. Indeed, solar panels can reduce 30–40 % heat load from solar radiation at its peak during the day. Sheep and cattle

seek shade under solar panels during high solar radiation, which lowers the increase in body surface temperature (Carvalho Fonsêca et al., 2023; Faria et al., 2023).

In case of very hot weather, animals may be moved indoors during the day to avoid the hottest hours, and they may graze at night (Fournel, Ouellet, & Charbonneau, 2017).

In the northern hemisphere, pastures or outdoor paddocks exposed south, west, or south-west receive the most solar radiation. To mitigate against heat stress, animals can be kept at pastures with lower exposure to solar radiation (reviewed by T.M. Brown-Brandl, 2013). Similarly, in summer, air temperature in hutches can be above the TNZ for calves; it is therefore recommended to place them facing north or east (Bakony, Jurkovich, Kiss, & Kovács, 2021).

7.1.2.2 Accelerating convection

Heat losses by convection can be increased indoors using fans or optimising barn ventilation on the condition that the air is cooler than the animal. Barns for ruminants typically use natural ventilation, with air entering the barn from low openings on the building sides and going out of the building through openings on the building ridge (Hoff, 2013).

7.1.2.3 Facilitating evaporation and conduction

The principle of evaporation can be used to cool the air that enters a barn. This can be obtained with fans equipped with sprinklers (Bleizgys, Naujokienė, & Čėsna, 2022). Evaporation is more often targeted at the animals, i.e. water from the skin surface evaporating thus allowing animals to decrease their body temperature. Evaporation from animals can be increased using sprinklers and increasing air speed with fans (D'Emilio, Porto, Cascone, Bella, & Gulino, 2017; Pérez-Barbería et al., 2021; Vitali, Grossi, & Lacetera, 2024). To be more effective, the water must enter the hair coat rather than staying at its surface. Therefore, misters are considered less effective to increase evaporation than sprinklers (Mitloehner et al., 2001, cited by T.M. Brown-Brandl, 2013). Spraying water with sprinklers abates body temperature by evaporation and conduction (Tresoldi, Schütz, & Tucker, 2018).

Wallowing and bathing are natural behaviours of water buffaloes to combat hot weather (Napolitano, Pacelli, Grasso, Braghieri, & De Rosa, 2013). In farm conditions, buffaloes may not have access to water and mud to perform such behaviours and should be sprayed with cool water in case of hot weather (Bah, Shahid, Pasha, & Javed, 2022). A pool with cool water has nevertheless been used with success to reduce heat stress in Alpacas in a zoo in a hot region whereas Alpacas are native to cold regions and suffer from heat (Peng, Fu, Lee, & Tsai, 2019).

Water is more conductive than organic material like straw. The litter or the ground must be kept clean from manure and drained to reduce heat load (reviewed by Brown-Brandl, 2013). When misters and sprinklers are used, proper drainage of the facilities must be ensured to avoid stagnant water.

7.2 Protection against cold

In cold conditions, one can act by increasing heat production by animals, limiting heat losses (by convection, conduction, or evaporation), and providing extra heat.

7.2.1 Increasing the production of heat by the animal

In ruminants, the digestion of roughage increases metabolic heat production. Therefore, their diet should contain a large proportion of roughage in cold weather. At the same time the animals need more energy to maintain their body temperature. It is thus essential that roughage of good quality is offered and in large amounts.

In ruminants, drinking very cold water can affect ruminal fermentation (by decreasing the ruminal temperature). Animals tend to drink less during cold weather. Thus, ruminants and equines should be provided warm water (e.g. 31 °C, Petersen, Muscha, Mulliniks, & Roberts, 2016) in cold conditions. In some cold regions, heated drinkers are used, which avoid freezing of the water and optimise water intake.

Finally, maintaining animals in groups rather than alone allows them to benefit from the heat of others; this is particularly true for young animals that stay with their dam.

7.2.2 Limiting heat losses

The impact of cold ambient temperatures is increased by exposure to wind and precipitation. Indoor housing protects the animals against wind, rain and snow. Alternatively, animals, except young ones, can stay outdoors in case of cold weather in European conditions, provided they have access to shelter (Van Laer, Moons, Sonck, & Tuyttens, 2014). The shelter should be oriented to protect animals against dominant winds. Animals can also use natural shelter from trees and bushes (Van Laer et al., 2015). Vulnerable animals, including young animals, may require extra protection with jackets. Deep bedding buffers the animals from a cold floor or ground, limiting heat loss by conduction.

7.2.3 Providing extra heat

In most EU countries, ruminants and equines do not need other measures than those mentioned above to resist cold. This, however, is not true for young animals (e.g. calves, lambs, kids). Radiant heat lamps are often used for these animals (Hoff, 2013), which transfer heat to animals by radiation.

7.2.4 Special case: parturition and neonates

Neonates are very sensitive to thermal conditions, especially cold. In case of cold conditions (below TNZ), it is essential that neonates are kept in a well-bedded shelter that provides protection from wind / air draughts and that they are fed increased amounts of colostrum or milk (reviewed by Silva *et al*., 2021). The bedding, e.g. straw, should be dry and deep enough to allow neonates to nestle into it. The energy requirements of neonates are higher during cold ambient temperature; for instance, at -10°C, the energy requirement for body maintenance of a calf is twice that at 20 °C (Drackley, 2008). Colostrum is very nutritive and helps the neonate to cope with cold (Fernanda Lavinia Moura Silva et al., 2021). An additional provision of colostrum is necessary when the

ambient temperature drops below LCT. In addition, as mentioned above, radiant lamps can help young animals keep warm. Neonates born from a dystocial parturition and twin neonates are especially sensitive to cold because of a low heat production resulting from a low mobilisation of body lipids due to low plasma thyroid hormone levels (Masters et al., 2023; Vermorel, Dardillat, Vernet, Davicco, & Demigne, 1983). They should thus receive extra care in cold conditions.

In case parturition is likely to take place during cold weather, it is important that females receive increased amounts of food during the last third of gestation to ensure adequate production of colostrum to protect the neonate. When approaching parturition, females should be able to isolate from the rest of the herd, e.g. they can be placed in a parturition pen with a clean, dry and deep bedding and with protection against draughts. The neonate must be carefully monitored: if the dam does not lick the neonate, it must be dried, and the intake of colostrum must be checked. As a last resort, e.g. if the calf is weak, colostrum may be provided via an oesophageal tube (See thematic factsheet 'Colostrum provision to calves').

8 Key factors to focus on during welfare inspections

Animal-based measures, such as behaviour (e.g. changes in lying vs. standing time, animals gathering, searching for sun vs. shade), respiration, and body temperature, can be used to assess if animals suffer from cold or heat stress. One can also consider ambient parameters (temperature, humidity, air speed and radiation). However, it is unlikely that an inspector will be present on the days when thermal stress occurs. Therefore, it is important to assess the risk for thermal stress according to the season, the region and activity (e.g. production system). There is more risk for an animal to suffer from cold stress in Nordic or mountainous regions, especially in winter, and from heat stress in Mediterranean regions, especially in summer. Depending on the most prevalent risks (cold vs. heat stress), mitigation strategies (e.g. shelter, ventilation, modification of the diet) must be considered (Tables 2 & 3).

Table 2: Indicators of cold and heat stress

Area	Indicators of risks of cold stress	Indicators of risks of heat stress
Animal[1]	Decreased body core temperature	Increased body core temperature
	Goose bumps, piloerection	Increased skin temperature
	Shivering	Sweating
	Vasoconstriction	Panting
	Increased heart rate	Increased respiratory rate
		Reduced feed intake
		Reduced milk production
		Decreased fertility
	Increased glycemia[2]	Increased cortisol[2]
	Increased time spent lying	Increased time spent standing
Ambient conditions	Temperature below LCT	Temperature above UCT
	Humidity	Humidity
	Air speed (negative impact)	Air speed (positive impact)
		Solar radiation
Risks (depending on region & season)	Estimated frequency of cold days	Estimated frequency of heat days

[1]Animal's reactions to cold vs. heat vary with species
[2]Not applicable during on-farm inspection

Table 3: Indicators of mitigation strategies

	Mitigation strategies against cold	Mitigation strategies against heat
Protections in place	Large amounts of good quality roughage in diet	Low-fibre diet
		Feeding during coolest hours
	Warm drinking water	Cool drinking water
	Animals in groups	Large space allowance / animal
	Protection against wind, shelter	Increase in convection and evaporation: Ventilation and fans possibly combined with sprinklers in barns; pool with cool water for buffaloes
		Protection against radiation: shade; cool roofs; hutches, paddocks, pastures exposed north to east
	Deep bedding	Dry litter or ground
	For young animals: radiant lamps, jackets	Avoidance of physical exercise (handling, moving, transport, work)

9 Gaps in knowledge and further studies needed

The following gaps in knowledge were identified:

- Lack of information for some species or animal types:
  - young animals (e.g. lambs, goat kids)
  - heifers. They may adapt to cold more than calves but do not generate as much heat as lactating cows and thus may adapt less to cold stress but more easily to heat stress than cows.
  - cervids
  - donkeys and equine hybrids
- Lack of information on LCT (specially depending on animal age)
- Need to move from THI to more sophisticated indices e.g. to include radiation, air speed (e.g. HLI)
- Need to consider the accumulated effect of heat (e.g. using AHL)
- Need to clarify the concept of thermal comfort zones/degrees of thermal stress and validate animal-based measures: these zones depend not only on environmental conditions but also on the potential of adaptation of animals (according to species, age and production phase).

10 Conclusions

Thermal comfort is becoming a pressing issue in most European countries due to climate change that has increased average temperatures and the frequency and duration of heat waves. In general, farmed ruminants and equines show signs of thermal discomfort in the case of heat (polypnea, panting, release of stress hormones, behavioural changes (e.g. changes in lying and standing time), reduction in feed intake and in dairy animals, reduction in milk production). Heat stress should be mitigated by providing shade and shelter outdoors and ventilation in housing. Water sprinklers should also be considered for species and in regions most prone to heat waves. Additionally, access to cool or cold water, and limiting handling and physical exercise, as well as adapting diet and feeding management are key mitigation strategies for heat stress.

By contrast, in winter, animals may be subjected to cold stress, especially when temperatures fall below 0 °C. Draughts and humidity should be avoided to limit the effects of cold while deep bedding helps animals to maintain their body temperature. Young animals are more sensitive to cold and can require supplementary heating.

11 References

Abdoun, K. A., Samara, E. M., Okab, A. B., & Al-Haidary, A. I. (2012). A Comparative Study on Seasonal Variation in Body Temperature and Blood Composition of Camels and Sheep. *Journal of Animal and Veterinary Advances, 11*(6), 769-773. doi:10.3923/javaa.2012.769.773

Akyuz, A., Boyaci, S., & Cayli, A. (2010). Determination of Critical Period for Dairy Cows Using Temperature Humidity Index. *Journal of Animal and Veterinary Advances, 9*(13), 1824-1827. doi:10.3923/javaa.2010.1824.1827

Al-Ramamneh, D. (2023). Thermoregulation in sheep and goats: A review. *Asian Journal of Biology*, 34-42. doi:10.9734/ajob/2023/v17i1315

Alhaidary, A., Samara, E., Okab, A., & Abdoun, K. (2013). Thermophysiological responses and heat tolerance of Saudi camel breeds. *International Journal of Chemical, Environmental & Biological Sciences (IJCEBS), 1*, 173-176. doi:none

Armstrong, D. V. (1994). Symposium - Nutrition and Heat-Stress Heat-Stress Interaction with Shade and Cooling. *Journal of Dairy Science, 77*(7), 2044-2050. doi:10.3168/jds.S0022-0302(94)77149-6

Bah, M., Shahid, M. Q., Pasha, T. N., & Javed, K. (2022). Performance and welfare of dairy buffaloes subjected to different cooling strategies during subtropical summer. *Tropical Animal Health and Production, 54*(1), 51. doi:10.1007/s11250-022-03055-4

Bakony, M., Jurkovich, V., Kiss, G., & Kovács, L. (2021). The effect of hutch compass direction on primary heat stress responses in dairy calves in a continental region. *Animal Welfare, 30*(3), 315-324. doi:10.7120/09627286.30.3.009

Baldi, M., Dalu, G., Maracchi, G., Pasqui, M., & Cesarone, F. (2006). Heat waves in the mediterranean: A local feature or a larger-scale effect? *International Journal of Climatology, 26*(11), 1477-1487. doi:10.1002/joc.1389

Beatty, D. T., Barnes, A., Taylor, E., Pethick, D., McCarthy, M., & Maloney, S. K. (2006). Physiological responses of *Bos taurus* and *Bos indicus* cattle to prolonged, continuous heat and humidity. *Journal of Animal Science, 84*(4), 972-985. doi:10.2527/2006.844972x

Becker, C. A., Collier, R. J., & Stone, A. E. (2020). Invited review: Physiological and behavioral effects of heat stress in dairy cows. *Journal of Dairy Science, 103*(8), 6751-6770. doi:10.3168/jds.2019-17929

Beede, D. K., & Collier, R. J. (1986). Potential nutritional strategies for intensively managed cattle during thermal-stress. *Journal of Animal Science, 62*(2), 543-554. doi:DOI 10.2527/jas1986.622543x

Berihulay, H., Abied, A., He, X. H., Jiang, L., & Ma, Y. H. (2019). Adaptation mechanisms of small ruminants to environmental heat stress. *Animals, 9*(3), 75. doi:10.3390/ani9030075

Berman, A. (2005). Estimates of heat stress relief needs for Holstein dairy cows. *Journal of Animal Science, 83*(6), 1377-1384. doi:10.2527/2005.8361377x

Bleizgys, R., Naujokienė, V., & Čėsna, J. (2022). Humidification–cooling system in semi-insulated box-type cowsheds prevent the loss of milkpProductivity due to thermal stress. *Agronomy, 12*(5), 1131. doi:10.3390/agronomy12051131

Bröde, P., Fiala, D., Blazejczyk, K., Holmér, I., Jendritzky, G., Kampmann, B., . . . Havenith, G. (2012). Deriving the operational procedure for the Universal Thermal Climate Index (UTCI). *International Journal of Biometeorology, 56*(3), 481-494. doi:10.1007/s00484-011-0454-1

Broucek, J. (2009). Effect of high temperature on milk production of cows from free -stall housing with natural ventilation. *Slovak J. Anim. Sci., 42*, 167-173.

Brown-Brandl, T. M. (2013). Managing thermal stress in feedlot cattle: environment, animal susceptibility and management options from a US perspective. In A. Aland & T. Banhazi (Eds.), *Livestock housing: modern management to ensure optimal health and welfare of farm animal* (pp. 189-208). Wageningen, the Netherlands: Wageningen Academic Publishers.

Brown-Brandl, T. M., Nienaber, J. A., Eigenberg, R. A., Hahn, G. L., & Freetly, H. (2003). Thermoregulatory responses of feeder cattle. *Journal of Thermal Biology, 28*(2), 149-157. doi:10.1016/S0306-4565(02)00052-9

Carabaño, M., Ramon, M., Díaz, C., Molina Alcalá, A., Pérez-Guzmán, M., & Serradilla, J. (2017). Breeding and genetics symposium: Breeding for resilience to heat stress effects in dairy ruminants. A comprehensive review. *Journal of Animal Science, 95*, 1813-1826. doi:10.2527/jas.2016.1114

Carvajal, M. A., Alaniz, A. J., Gutiérrez-Gómez, C., Vergara, P. M., Sejian, V., & Bozinovic, F. (2021). Increasing importance of heat stress for cattle farming under future global climate scenarios. *Science of The Total Environment, 801*, 149661. doi:10.1016/j.scitotenv.2021.149661

Carvalho Fonsêca, V. d. F., de Andrade Culhari, E., Moura, G. A. B., Nascimento, S. T., Milan, H. M., Neto, M. C., & Maia, A. S. C. (2023). Shade of solar panels relieves heat load of sheep. *Applied Animal Behaviour Science, 265*, 105998. doi:10.1016/j.applanim.2023.105998

Collier, R. J., Baumgard, L. H., Zimbelman, R. B., & Xiao, Y. (2019). Heat stress: physiology of acclimation and adaptation. *Animal Frontiers, 9*(1), 12-19. doi:10.1093/af/vfy031

Collier, R. J., Doelger, S. G., Head, H. H., Thatcher, W. W., & Wilcox, C. J. (1982). Effects of heat-stress during pregnancy on maternal hormone concentrations, calf birth-weight and postpartum milk-yield of Holstein cows. *Journal of Animal Science, 54*(2), 309-319.

Copernicus Climate Change Service (C3S). (2024). *European State of the Climate 2023, Summary*. Retrieved from https://doi.org/10.24381/bs9v-8c66

D'Emilio, A., Porto, S. M. C., Cascone, G., Bella, M., & Gulino, M. (2017). Mitigating heat stress of dairy cows bred in a free-stall barn by sprinkler systems coupled with forced ventilation. *Journal of Agricultural Engineering, 48*(4), 190-195. doi:10.4081/jae.2017.691

De, K., Kumar, D., Sharma, S., Kumawat, P., Mohapatra, A., & Sahoo, A. (2020). Effect of drinking earthen pot water on physiological response and behavior of sheep under heat stress. *Journal of Thermal Biology, 87*, 102476. doi:10.1016/j.jtherbio.2019.102476

Desrousseaux, G. (2021). Fighting heat stress in dairy cows with a new holistic concept. *AFMA Matrix,, 30*(4), 63-65. doi:10.10520/ejc-vp_afma_v30_n4_a15

Doubek, J., Slosárková, S., Fleischer, P., Malá, G., & Skrivánek, M. (2003). Metabolic and hormonal profiles of potentiated cold stress in lambs during early postnatal period. *Czech Journal of Animal Science, 48*(10), 403-411. doi:none

Drackley, J. K. (2008). Calf nutrition from birth to breeding. *Veterinary Clinics of North America-Food Animal Practice, 24*(1), 55-86. doi:10.1016/j.cvfa.2008.01.001

Edwards-Callaway, L. N., Cramer, M. C., Cadaret, C. N., Bigler, E. J., Engle, T. E., Wagner, J. J., & Clark, D. L. (2020). Impacts of shade on cattle well-being in the beef supply chain. *Journal of Animal Science, 99*(2), 1-21. doi:10.1093/jas/skaa375

EFSA Panel on Animal Health and Animal Welfare (AHAW), Saxmose Nielsen, S., Alvarez, J., Bicout, D. J., Calistri, P., Canali, E., . . . Winckler, C. (2023). Welfare of calves. *EFSA Journal, 21*(3), 7896. doi:10.2903/j.efsa.2023.7896

EFSA Panel on Animal Health and Welfare, Algers, B., Blokhuis, H. J., Broom, D. M., Capua, I., Cinotti, S., . . . Wooldridge, M. (2006). Scientific opinion on the risk of poor welfare in intensive calf farming systems: An update of the Scientific Veterinary Committee Report on the Welfare of calves. *The EFSA Journal, 366*, 1-144. doi:10.2903/j.efsa.2006.366

EFSA Panel on Animal Health and Welfare, Nielsen, S. S., Alvarez, J., Bicout, D. J., Calistri, P., Canali, E., . . . Michel, V. (2021). Welfare of sheep and goats at slaughter. *The EFSA Journal, 19*(11), e06882. doi:10.2903/j.efsa.2021.6882

EFSA Panel on Animal Health and Welfare, Nielsen, S. S., Alvarez, J., Bicout, D. J., Calistri, P., Canali, E., . . . Herskin, M. (2022). Welfare of equidae during transport. *The EFSA Journal, 20*(9), e07444. doi:10.2903/j.efsa.2022.7444

Efthymiadis, D., Goodess, C. M., & Jones, P. D. (2011). Trends in Mediterranean gridded temperature extremes and large-scale circulation influences. *Natural Hazards and Earth System Sciences, 11*(8), 2199-2214. doi:10.5194/nhess-11-2199-2011

El Mahdy, C., Boaru, A., Popescu, S., & Borda, C. (2016). Water quality, essential condition sustaining the health, production and reproduction in cattle. A review. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Animal Science and Biotechnologies, 73*, 1843-1536. doi:10.15835/buasvmcn-asb:12156

Elayadeth-Meethal, M., & Kolathingal-Thodika, N. (2025). Comparative physiological and biochemical assessment of the heat tolerance of dwarf Vechur, Kasaragod, and standard-size crossbred cattle under humid, hot conditions. *International Journal of Biometeorology, 69*(3), 643-657. doi:10.1007/s00484-024-02845-9

European Environment Agency. (2024). *European climate risk assessment EEA report 01/2024*. Retrieved from https://www.preventionweb.net/publication/european-climate-risk-assessment

Faria, A. F. P. A., Maia, A. S. C., Moura, G. A. B., Fonsêca, V. F. C., Nascimento, S. T., Milan, H. F. M., & Gebremedhin, K. G. (2023). Use of solar panels for shade for Holstein heifers. *Animals, 13*(3), 329. doi:10.3390/ani13030329

Foroushani, S., & Amon, T. (2022). Thermodynamic assessment of heat stress in dairy cattle: lessons from human biometeorology. *International Journal of Biometeorology, 66*(9), 1811-1827. doi:10.1007/s00484-022-02321-2

Fournel, S., Ouellet, V., & Charbonneau, É. (2017). Practices for alleviating heat stress of dairy cows in humid continental climates: A literature review. *Animals, 7*(5), 37. doi:10.3390/ani7050037

Gantner, V., Mijic, P., Kuterovac, K., Solic, D., & Gantner, R. (2011). Temperature-humidity index values and their significance on the daily production of dairy cattle. *Mljekarstvo, 61*(1), 56-63. doi:none

Gaughan, J. B., Mader, T. L., Holt, S. M., & Lisle, A. (2008). A new heat load index for feedlot cattle. *Journal of Animal Science, 86*(1), 226-234. doi:10.2527/jas.2007-0305

Giorgi, F. (2006). Climate change hot-spots. *Geophysical Research Letters, 33*(8), L08707. doi:10.1029/2006gl025734

Giorgi, F., & Lionello, P. (2008). Climate change projections for the Mediterranean region. *Global and Planetary Change, 63*(2-3), 90-104. doi:10.1016/j.gloplacha.2007.09.005

Guo, H., Zhou, G., Tian, G., Liu, Y., Dong, N., Li, L., . . . Yang, Y. (2021). Changes in rumen microbiota affect metabolites, immune responses and antioxidant enzyme activities of sheep under cold stimulation. *Animals, 11*(3), 712. doi:10.1029/2006GL025734

Habte, M., Eshetu, M., Maryo, M., Andualem, D., Legesse, A., & Admassu, B. (2021). The influence of weather conditions on body temperature, milk composition and yields of the free-ranging dromedary camels in Southeastern rangelands of Ethiopia. *Cogent Food & Agriculture, 7*(1), 1930932. doi:10.1080/23311932.2021.1930932

Hahn, G. L. (1999). Dynamic responses of cattle to thermal heat loads. *Journal of Animal Science, 77*, 10-20. doi:10.2527/1997.77suppl_210x

Hahn, G. L., Mader, T. L., & Eigenberg, R. A. (2003). Perspective on development of thermal indices for animal studies and management. In N. Lacettera, U. Bermabucci, H. H. Khalifa, B. Ronchi, & A. Nardone (Eds.), *Interactions between Climate and Animal Production* (pp. 31-44): EAAP Technic Series.

Hammami, H., Bormann, J., M'hamdi, N., Montaldo, H. H., & Gengler, N. (2013). Evaluation of heat stress effects on production traits and somatic cell score of Holsteins in a temperate environment. *Journal of Dairy Science, 96*(3), 1844-1855. doi:10.3168/jds.2012-5947

Hansen, P. J. (2004). Physiological and cellular adaptations of zebu cattle to thermal stress. *Animal Reproduction Science, 82-83*, 349-360. doi:10.1016/j.anireprosci.2004.04.011

Hempel, S., Menz, C., Pinto, S., Galán, E., Janke, D., Estellés, F., . . . Amon, T. (2019). Heat stress risk in European dairy cattle husbandry under different climate change scenarios – uncertainties and potential impacts. *Earth Syst. Dynam., 10*(4), 859-884. doi:10.5194/esd-10-859-2019

Hoff, S. J. (2013). The impact of ventilation and thermal environment on animal health, welfare and performance. In A. Aland & T. Banhazi (Eds.), *Livestock housing: modern management to ensure optimal health and welfare of farm animal* (pp. 209-235). Wageningen, the Netherlands: Wageningen Academic Publishers.

Hussen, J. (2021). Changes in cell vitality, phenotype, and function of dromedary camel leukocytes after whole blood exposure to heat stress. *Frontiers in Veterinary Science, 8*, 647609. doi:10.3389/fvets.2021.647609

Hyde, R. M., Green, M. J., Hudson, C., & Down, P. M. (2022). The effect of environmental temperature on average daily gain in preweaned calves: A randomized controlled trial and Bayesian analysis. *Journal of Dairy Science, 105*(4), 3430-3439. doi:10.3168/jds.2021-21199

Jeffcott, L. B. (1996). Fifth International Conference on Equine Exercise Physiology. *Journal of Equine Veterinary Science, 16*(12), 522-&. doi:10.1016/S0737-0806(96)80007-4

Kalestone environmental. (2011). *Cattle Heat Load Forecast Service for 2005/2006 Summer* (Vol. Flot.334). Sydney, Australia: Meat & Livestock Australia Limited.

Kingma, B. R., Frijns, A. J., Schellen, L., & Van Marken Lichtenbelt, W. D. (2014). Beyond the classic thermoneutral zone: Including thermal comfort. *Temperature, 1*(2), 142–149. doi:10.4161/temp.29702

Kohli, S., Atheya, U. K., & Thapliyal, A. (2014). Assessment of optimum thermal humidity index for crossbred dairy cows in Dehradun district, Uttarakhand, India. *Veterinary World, 7*(11), 916–921. doi:10.14202/vetworld.2014.916-921

Kolacz, R. (2006). *Hygiene and Welfare of Farm Animals*: Agricultural University, Wroclaw.

Kumar, D., Singh, A. K., Sahoo, A., & Naqvi, S. M. K. (2014). Seasonal variation of physiological response in ewes of farmers' flocks under semi-arid tropical environment. *Biological Rhythm Research, 45*(3), 397-405. doi:10.1080/09291016.2013.830509

Leite, J. H. G. M., Façanha, D. A. E., Bermejo, J. V. D., Guilhermino, M. M., & Bermejo, L. A. (2021). Adaptive assessment of small ruminants in arid and semi-arid regions. *Small Ruminant Research, 203*, 106497. doi:10.1016/j.smallrumres.2021.106497

Li, S., Gebremedhin, K. G., Lee, C., & Collier, R. (2009). *Evaluation of Thermal Stress Indices for Cattle.* Paper presented at the ASABE Annual International Meeting Reno, Nevada.

Lima, A. R. C., Silveira, R. M. F., Castro, M. S. M., De Vecchi, L. B., da RochaFernandes, M. H. M., & de Resende, K. T. (2022). Relationship between thermal environment, thermoregulatory responses and energy metabolism in goats: A comprehensive review. *Journal of Thermal Biology, 109*, 103324. doi:10.1016/j.jtherbio.2022.103324

Mader, T. L., Davis, M. S., & Brown-Brandl, T. (2006). Environmental factors influencing heat stress in feedlot cattle. *Journal of Animal Science, 84*(3), 712-719. doi:10.2527/2006.843712x

Marai, I. F. M., El-Darawany, A. A., Fadiel, A., & Abdel-Hafez, M. A. M. (2007). Physiological traits as affected by heat stress in sheep - A review. *Small Ruminant Research, 71*(1-3), 1-12. doi:10.1016/j.smallrumres.2006.10.003

Marai, I. F. M., & Haeeb, A. A. M. (2010). Buffalo's biological functions as affected by heat stress - A review. *Livestock Science, 127*(2-3), 89-109. doi:10.1016/j.livsci.2009.08.001

Marlin, D., & Williams, J. (2018). Equine endurance race pacing strategy and performance in 120-km single-day races. *Journal of Equine Veterinary Science, 67*, 87-90. doi:10.1016/j.jevs.2018.03.013

Marlin, D. J., Misheff, M., & Whitehead, P. (2018). *Preparation for and management of horses and athletes during equestrian events held in thermally challenging environments.* Paper presented at the FEI sports forum, , Lausanne.

Mascarenhas, N. M. H., Furtado, D. A., de Souza, B. B., de Sousa, O. B., Costa, A. N. L. D., Feitosa, J. V., . . . Dornelas, K. C. (2023). Morphology of coat and skin of small ruminants reared in the Brazilian semi-arid region. *Journal of Thermal Biology, 112*. doi:10.1016/j.jtherbio.2022.103418

Masters, D. G., Blache, D., Lockwood, A. L., Maloney, S. K., Norman, H. C., Refshauge, G., & Hancock, S. N. (2023). Shelter and shade for grazing sheep: implications for animal welfare and production and for landscape health. *Animal Production Science, 63*(7), 623-644. doi:10.1071/AN22225

McManus, C. M., Lucci, C. M., Maranhao, A. Q., Pimentel, D., Pimentel, F., & Paiva, S. R. (2022). Response to heat stress for small ruminants: Physiological and genetic aspects. *Livestock Science, 263*, 105028. doi:10.1016/j.livsci.2022.105028

Morgan, K. (1998). Thermoneutral zone and critical temperatures of horses. *Journal of Thermal Biology, 23*(1), 59-61. doi:10.1016/S0306-4565(97)00047-8

Murphy, M., Davis, C., & McCoy, G. (1983). Factors affecting water consumption by Holstein cows in early lactation. *J. Dairy Sci., 66* 35-38. doi:none

Napolitano, F., Pacelli, C., Grasso, F., Braghieri, A., & De Rosa, G. (2013). The behaviour and welfare of buffaloes (*Bubalus bubalis*) in modern dairy enterprises. *Animal, 7*(10), 1704-1713. doi:10.1017/S1751731113001109

National Oceanic and Atmospheric Administration. (1976). *Livestock Hot Weather Stress*. Retrieved from Operations Manual Letter C-31-76, Department of Commerce, NOAA, National Weather Service Central Region, Kansas City:

National Research Council. (1971). *A guide to environmental research on animals*. Washington: National Academy of Sciences Washington.

Neves, M., Azevedo, M., Costa, L., Guim, A., Leite, A., & Chagas, J. (2009). Níveis críticos do Índice de Conforto Térmico para ovinos da raça Santa Inês criados a pasto no agreste do Estado de Pernambuco. *Acta Scientiarum. Animal Sciences, 31*(2), 169-175. doi:10.4025/actascianimsci.v31i2.3766

Nienaber, J. A., & LeRoy Hahn, G. (2004). *Engineering and management practices to ameliorate livestock heat stress.* Paper presented at the International symposium of CIGR New Trends in Farm Buildings, Evora, Portugal.

Olsson, K. (2005). Fluid balance in ruminants: Adaptation to external and internal challenges. *Trends in Comparative Endocrinology and Neurobiology, 1040*, 156-161. doi:10.1196/annals.1327.020

Parish, J. A., Carroll, J. A., Broadway, P., Best, T., Stewart, C., & Burdick Sanchez, N. C. (2016). Hair shedding score and hair coat color affect body temperature during heat stress in weaned beef heifers. *Journal of Animal Science, 95, no. suppl_1*, 34. doi:10.2527/ssasas2017.068

Patel, J. H., Rajput, M. B., & Bariya, A. R. (2016). Adaptive physiological and biochemical responses of dairy animals to heat stress: A review. *International Journal of Applied and Natural Sciences, 5*(1), 107-116. doi:none

Payne, W. J. A., & Williamson, G. (1990). *An Introduction to Animal Husbandry in the Tropics, 4th ed*: Harlow, Essex, England: New York: Longman Scientific & Technical ; Wiley.

Peng, S., Fu, E., Lee, S., & Tsai, S. (2019). Methods to ameliorate heat stress in non-native alpaca, *Vicugna pacos*. *Small Ruminant Research, 175*, 90-95. doi:10.1016/j.smallrumres.2019.04.015

Pérez-Barbería, F. J., Arroyo-González, I., García, A. J., Serrano, M. P., Gallego, L., & Landete-Castillejos, T. (2021). Water sprinkling as a tool for heat abatement in farmed Iberian red deer: Effects on calf growth and behaviour. *Plos One, 16*(4), e0249540. doi:10.1371/journal.pone.0249540

Pérez-Barbería, F. J., García, A. J., Cappelli, J., Landete-Castillejos, T., Serrano, M. P., & Gallego, L. (2020). Heat stress reduces growth rate of red deer calf: Climate warming implications. *Plos One, 15*(6), e0233809. doi:10.1371/journal.pone.0233809

Petersen, M. K., Muscha, J. M., Mulliniks, J. T., & Roberts, A. J. (2016). Water temperature impacts water consumption by range cattle in winter. *Journal of Animal Science, 94*(10), 4297-4306. doi:10.2527/jas.2015-0155

Polsky, L., & von Keyserlingk, M. A. G. (2017). Invited review: Effects of heat stress on dairy cattle welfare. *J Dairy Sci, 100*(11), 8645-8657. doi:10.3168/jds.2017-12651

Rashamol, V. P., Veerasamy, S., Bagath, M., Krishnan, G., Archana, R., & Bhatta, R. (2018). Physiological adaptability of livestock to heat stress: An updated review. *Journal of Animal Behaviour and Biometeorology, 6*, 62-71. doi:10.26667/2318-1265jabb.v6n3p62-71

Ratnakaran, A., Sejian, V., Jose, V., Vaswani, S., Madiajagan, B., Krishnan, G., . . . Bhatta, R. (2016). Behavioral responses to livestock adaptation to heat stress challenges. *Asian Journal of Animal Sciences, 11*, 1-13. doi:10.3923/ajas.2017.1.13

Ravagnolo, O., Misztal, I., & Hoogenboom, G. (2000). Genetic component of heat stress in dairy cattle, development of heat index function. *Journal of Dairy Science, 83*(9), 2120-2125. doi:10.3168/jds.S0022-0302(00)75094-6

Rensis, F. D., & Scaramuzzi, R. J. (2003). Heat stress and seasonal effects on reproduction in the dairy cow—a review. *Theriogenology, 60*(6), 1139–1151. doi:10.1016/S0093-691X(03)00126-2

Roland, L., Drillich, M., Klein-Jöbstl, D., & Iwersen, M. (2016). Invited review: Influence of climatic conditions on the development, performance, and health of calves. *Journal of Dairy Science, 99*(4), 2438-2452. doi:10.3168/jds.2015-9901

Salama, A. A. K., Caja, G., Hamzaoui, S., Badaoui, B., Castro-Costa, A., Façanha, D. A. E., . . . Bozzi, R. (2014). Different levels of response to heat stress in dairy goats. *Small Ruminant Research, 121*(1), 73-79. doi:10.1016/j.smallrumres.2013.11.021

Samara, E., & Alhaidary, A. (2014). *Estimating the thermoneutral zone of dromedary camels using surface heat transfer modelling.* Paper presented at the 20th international congress of biometeorology, Cleveland, Ohio.

Santos, M., Souza-Junior, J., Dantas, M., & Costa, L. L. (2021). An updated review on cattle thermoregulation: physiological responses, biophysical mechanisms, and heat stress alleviation pathways. *Environmental Science and Pollution Research, 28*, 30471–30485. doi:10.1007/s11356-021-14077-0

Santunione, G., Libbra, A., & Muscio, A. (2017). Cool roofs with high solar reflectance for the welfare of dairy farming animals. *IOP Conf. Series: Journal of Physics: Conf. Series, 796*, 012028. doi:10.1088/1742-6596/796/1/012028

Schlader, Z. J., Simmons, S. E., Stannard, S. R., & Mündel, T. (2011). The independent roles of temperature and thermal perception in the control of human thermoregulatory behavior. *Physiology and Behavior, 103*(2), 217-224. doi:10.1016/j.physbeh.2011.02.002

Schroter, R. C., Marlin, D. J., & Jeffcott, L. B. (1996). Use of the wet bulb globe temperature (WBGT) index to quantify environmental heat loads during three-day-event competitions. *Equine Vet J, 28*(S22), 3–6. doi:10.1111/j.2042-3306.1996.tb05025.x

Schüller, L. K., Burfeind, O., & Heuwieser, W. (2014). Impact of heat stress on conception rate of dairy cows in the moderate climate considering different temperature-humidity index thresholds, periods

relative to breeding, and heat load indices. *Theriogenology, 81*(8), 1050-1057. doi:10.1016/j.theriogenology.2014.01.029

Sejian, V., Bhatta, R., Gaughan, J. B., Dunshea, F. R., & Lacetera, N. (2018). Review: Adaptation of animals to heat stress. *Animal, 12(s2)*, S431-S444. doi:10.1017/S1751731118001945

Sejian, V., Krishnan, G., Bagath, M., Vaswani, S., Pragna, P., Aleena, J., . . . Bhatta, R. (2017). Measurement of severity of heat stress in sheep. In S. V., B. R., G. J., M. P.K., N. S.M.K., & L. R. (Eds.), *Sheep Production Adapting to Climate Change* (pp. 307-318). Singapore: Springer-Verlag, GMbH Publisher.

Sejian, V., Silpa, M. V., Reshma Nair, M. R., Devaraj, C., Krishnan, G., Bagath, M., . . . Bhatta, R. (2021). Heat stress and goat welfare: Adaptation and production considerations. *Animals, 11*(4), 1021.

Shaji, S., Niyas, P., Chaidanya, K., Sejian, V., & Bhatta, R. (2015). Ameliorative strategies to sustain livestock production during heat stress. *J. Vet. Sci. Med. Diagn, 4*(3), 1-6. doi:10.4172/2325-9590.1000161

Shoshani, E., & Hetzroni, A. (2013). Optimal barn characteristics for high-yielding Holstein cows as derived by a new heat-stress model. *Anim Behav Abst, 7*(1), 176-182. doi:10.1017/S1751731112001085

Silanikove, N. (2000). Effects of heat stress on the welfare of extensively managed domestic ruminants. *Livestock Production Science, 67*(1-2), 1-18. doi:none

Silanikove, N., & Koluman, N. (2015). Impact of climate change on the dairy industry in temperate zones: Predications on the overall negative impact and on the positive role of dairy goats in adaptation to earth warming. *Small Ruminant Research, 123*(1), 27-34. doi:10.1016/j.smallrumres.2014.11.005

Silva, F. L. M., & Bittar, C. M. M. (2019). Thermogenesis and some rearing strategies of dairy calves at low temperature - a review. *Journal of Applied Animal Research, 47*(1), 115-122. doi:10.1080/09712119.2019.1580199

Silva, F. L. M., Miqueo, E., Silva, M. D. d., Torrezan, T. M., Rocha, N. B., Salles, M. S. V., & Bittar, C. M. M. (2021). Thermoregulatory Responses and Performance of Dairy Calves Fed Different Amounts of Colostrum. *Animals, 11*(3), 703. doi:10.3390/ani11030703

Soppela, P., Nieminen, M., & Timisjàrvi, J. (1986). Thermoregulation in reindeer *Rangifer, Special Issue No. 1*, 273-278. doi:10.7557/2.6.2.659

Sossidou, E., Termatzidou, S. A., Marinou, K., Cerasoli, F., & Collins, J. (2024). *Review - Welfare of working equids in the European Union*. Retrieved from https://www.eurcaw-ruminants-equines.eu/wp-content/uploads/2024/07/REV-Ruminants-Equines-2023-04-EN-Working-Equids.pdf

Terrien, J., Perret, M., & Aujard, F. (2011). Behavioral thermoregulation in mammals: a review. *Frontiers in Bioscience-Landmark, 16*, 1428-1444. doi:10.2741/3797

The Commission for Thermal Physiology of the International Union of Physiological Sciences (IUPS Thermal Commission). (2001). Glossary of terms for thermal physiology. *The Japanese Journal of Physiology, 51*(2), 245-280. doi:none

Toussaint, G. (1997). The housing of milk goats. *Livestock Production Science, 49*(2), 151-164. doi:Doi 10.1016/S0301-6226(97)00011-0

Tresoldi, G., Schütz, K. E., & Tucker, C. B. (2018). Cooling cows with sprinklers: Timing strategy affects physiological responses to heat load. *Journal of Dairy Science, 101*(12), 11237-11246. doi:10.3168/jds.2018-14917

Ulbrich, U., Lionello, P., Belusic, D., Jacobeit, J., Knippertz, P., Kuglitsch, F. G., . . . et al. (2012). Climate of the Mediterranean: synoptic patterns, temperature, precipitation, winds, and their extremes. In P. Lionello (Ed.), *The climate of the Mediterranean region: from the past to the future* (pp. 301–346). Amsterdam (the Netherlands): Elsevier.

Umar, S., Munir, M. T., Azeem, T., Ali, S., Umar Phd, W., Rehman, A., & Shah, M. (2014). Effects of water quality on productivity and performance of livestock: A mini review. *Veterinaria, 2*, 11-15. doi:10.15835/buasvmcn-asb: 12156

Van Laer, E., Moons, C. P. H., Ampe, B., Sonck, B., Vangeyte, J., & Tuyttens, F. A. M. (2015). Summertime use of natural versus artificial shelter by cattle in nature reserves. *Animal Welfare, 24*(3), 345-356. doi:10.7120/09627286.24.3.345

Van Laer, E., Moons, C. P. H., Sonck, B., & Tuyttens, F. A. M. (2014). Importance of outdoor shelter for cattle in temperate climates. *Livest Sci, 159*, 87-101. doi:10.1016/j.livsci.2013.11.003

Veissier, I., Van Iaer, E., Palme, R., Moons, C. P. H., Ampe, B., Sonck, B., . . . Tuyttens, F. A. M. (2018). Heat stress in cows at pasture and benefit of shade in a temperate climate region. *International Journal of Biometeorology, 62*(4), 585-595. doi:10.1007/s00484-017-1468-0

Vermorel, M., Dardillat, C., Vernet, J., Davicco, M.-J., & Demigne, C. (1983). Energy metabolism and thermoregulation in the newborn calf. *Annales de Recherches Vétérinaires, 14*(4), 382-389. doi:none

Vitali, A., Grossi, G., & Lacetera, N. (2024). Vaginal temperature of lactating cows during heat waves or normal summer day and effect of additional daily cooling treatments as heat load mitigation strategy. *International Journal of Biometeorology, 68*(3), 419-426. doi:10.1007/s00484-023-02600-6

Wang, S., Li, Q., Peng, J., & Niu, H. (2023). Effects of long-term cold stress on growth performance, behavior, physiological parameters, and energy metabolism in growing beef cattle. *Animals, 13*(10), 1619. doi:10.3390/ani13101619

Webster, J. (1984). *Calf Husbandry, Health and Welfare*: CRC Press.

Yasothai, R. (2014). Effect of climate on nutrient intake and metabolism and countering heat stress by nutritional manipulation. *Int J Environ Sci Te, 3*(5), 1685 – 1690. doi:none

Young, B. A. (1981). Cold stress as it affects animal production. *Journal of Animal Science, 52*(1), 154-163. doi:10.2527/jas1981.521154x

Yousef, M. K. e. (1985). *Stress Physiology in Livestock*: CRC Press, Boca Raton, Florida.

Zampieri, M., Russo, S., di Sabatino, S., Michetti, M., Scoccimarro, E., & Gualdi, S. (2016). Global assessment of heat wave magnitudes from 1901 to 2010 and implications for the river discharge of the Alps. *Science of The Total Environment, 571*, 1330-1339. doi:10.1016/j.scitotenv.2016.07.008

About EURCAW *Ruminants & Equines*

EURCAW *Ruminants & Equines* is the third European Union Reference Centre for Animal Welfare. It focuses on ruminant and equine welfare and legislation, and covers the entire life cycle from birth to the end of life. EURCAW *Ruminants & Equines*' main objective is a harmonised compliance with EU legislation regarding welfare in EU Member States. This includes:

- Directive 98/58/EC concerning the protection of animals kept on farms;
- Regulations 1/2005/EC and 1099/2009/EC concerning their protection during transport and slaughter;
- Directive 2010/63/EU concerning the protection of animals used for scientific purposes;
- Directive 2008/119/EC laying down minimum standards for the protection of calves.

EURCAW *Ruminants & Equines* supports:

- Inspectors of Competent Authorities (CAs);
- Ruminant and equine welfare policy workers;
- Bodies supporting CAs with scientific expertise, training, and communication.

Website and contact

EURCAW *Ruminants & Equines*' website offers relevant and actual information to support enforcement of ruminant and equine welfare legislation.

We offer a 'Questions to EURCAW' service for official inspectors, policy workers, and other personnel providing advice or support for official controls of ruminant and equine welfare in the EU. For more information go to https://www.eurcaw-ruminants-equines.eu/questions-to-eurcaw/.

Activities of EURCAW *Ruminants & Equines*

- Coordinated Assistance
  Providing support, networking and Questions to EURCAW;
- Welfare indicators, Assessment & Best Practice
  Identifying animal welfare indicators, including animal based, management based and resource-based indicators, that can be used to verify compliance with the EU legislation;
- Scientific and technical studies
  Preparing Scientific Reviews of knowledge on welfare topics and identify research needs;
- Training
  Developing training materials and training standards for official inspectors;
- Communication and Dissemination
  Increasing awareness of our outputs via the website, twitter, and newsletter;

Partners

EURCAW *Ruminants & Equines* receives funding from DG SANTE of the European Commission and represents a collaboration between the following six partner institutions:

- Swedish University of Agricultural Sciences, Sweden
- Istituto Zooprofilattico Sperimentale dell'Abruzzo e del Molise "G. Caporale", Italy
- French National Institute for Agriculture, Food, and Environment, France
- University of Natural Resources and Life Sciences, Vienna, Austria
- University College Dublin, Ireland
- Ellinikos Georgikos Organismos-Dimitra/Veterinary Research Institute, Greece