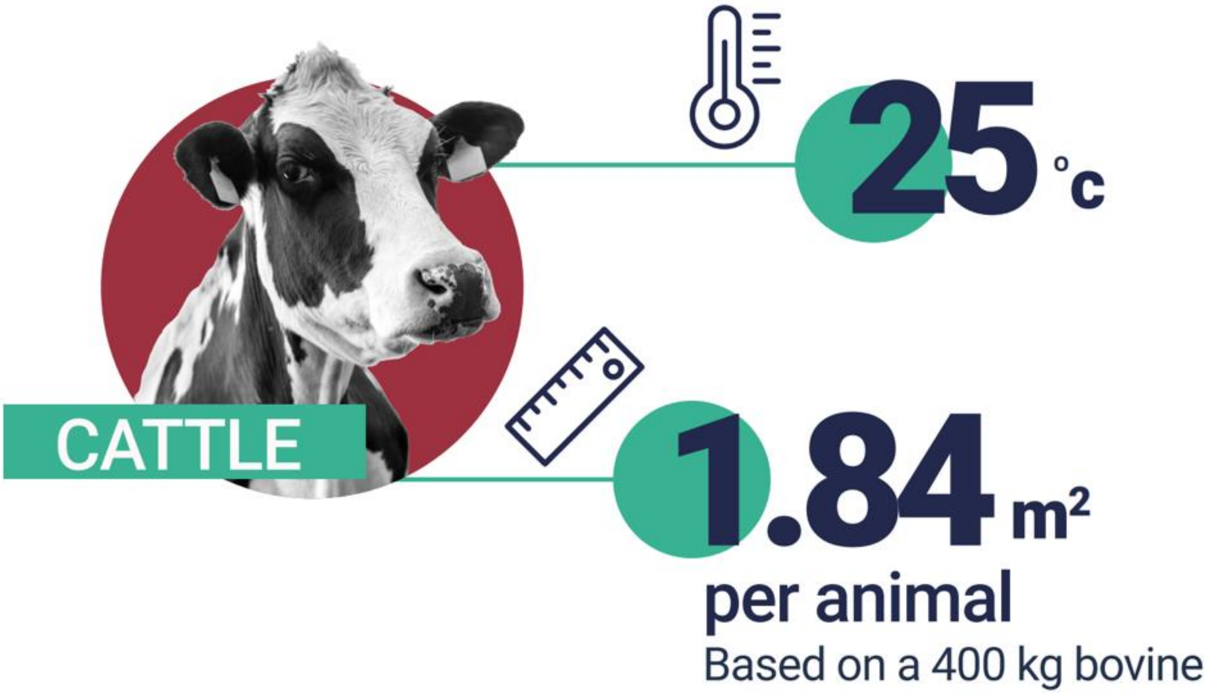
French Reference Centre for Animal Welfare




OPINION

# Thermal comfort, thermal stress factors and mitigating actions during the transport of cattle

## Original title in French

Confort thermique, facteurs de stress thermique et leviers d’action pendant le transport des bovins

Based on EFSA Opinion (2022b)

DECEMBER 2025

# Thermal comfort, thermal stress factors and mitigating actions during the transport of cattle

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Animal Welfare Office (BBEA) of the General Directorate for Food (DGAL), French Ministry of Agriculture and Food Sovereignty

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## Summary

This report by the French Reference Centre for Animal Welfare (FRCAW) summarises the key points of the EFSA Opinion on the Welfare of Cattle during Transport (EFSA, 2022b), and deals exclusively with information relating to thermal stress. This FRCAW report concentrates on three main areas. First, it details the physiological and behavioural mechanisms involved in the regulation of temperature in cattle. It then lists all those factors likely to generate thermal stress in cattle during transport. Last, the FRCAW proposes a number of mitigating actions to improve the thermal comfort of animals during the various stages of road transport: loading/unloading, transit, and journey breaks. The conclusion highlights the main points of the report and identifies directions for further research to 1) obtain an improved understanding of the thermal comfort conditions required by cattle (at all life stages) and 2) confirm that the suggested mitigating actions are appropriate.

## Keywords

Transport / Temperature / Thermal comfort / Thermal stress / Cattle / Thermoregulation

## Context as defined by the client

The draft revision of Regulation 1/2005 sets predicted external temperature limits that must be respected when deciding whether or not to authorise the transport of live animals of all species and breeds and in all locations.

Based on the known physiological parameters that determine the thermoneutral zones for those species most frequently transported in connection with an economic activity, is it possible to determine temperature/humidity ranges and levers/tools (ventilation, misting, etc.) that can be used during transport to adjust these parameters and improve the thermal comfort of these animals?

## Request

For the FRCAW to answer the following questions as fully as possible:

+ What are the thermoneutral zones for cattle [, pigs, poultry (broilers and layers), small ruminants (sheep and goats) and equines]?
+ What parameters (temperature, humidity, air flow, etc.) can be used to regulate the temperatures perceived by animals during transport?
+ How can these parameters be modified to improve the thermal comfort of the animals?

*The FRCAW will address only the transport of cattle by road in the present report.*

## Reference documents

+ COUNCIL REGULATION (EC) No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97
+ Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the protection of animals during transport and related operations, amending Council Regulation (EC) No 1255/97 and repealing Council Regulation (EC) No 1/2005 (2023)
+ EFSA AHAW Panel (2022b). Welfare of cattle during transport. EFSA Journal 2022;20(9):7442, 121 pp. https://doi.org/10.2903/j.efsa.2022.7442

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# Glossary (English version)

## Assembly centres

Places such as holdings, collection centres and markets, at which domestic Equidae or domestic animals of bovine, ovine, caprine or porcine species originating from different holdings are grouped together to form consignments (European Commission, 2018).

## Chimney effect or stack effect

Movement of air, where warm air rises and cold air sinks.

## Cold stress

The animal experiences stress and/or negative affective states such as discomfort and/or distress when exposed to low effective temperature (EFSA, 2022a).

## Conduction

Conduction is a mode of heat transfer that occurs through direct contact between two objects or surfaces of different temperatures, i.e., in the present context, between an animal and its surroundings via surfaces with which it is in direct contact. Heat loss from the animal by conduction can occur only if its body temperature is higher than that of the contact surface (see Serviento, 2022). This type of heat loss can therefore no longer occur during periods of extreme heat (Guingal, 2018).

## Control post

Places where animals are rested for at least 12 hours, in accordance with the rules on journey times and rest periods laid down in the European Regulations. These posts must be approved by the competent authorities (Consortium of the Animal Transport Guides Project, 2018).

## Convection

Convection is a method of heat transfer that involves the movement of fluids (including blood and air) that transport thermal energy from one area to another. In particular, it increases an animal's loss of body heat through the circulation of air around an animal. By increasing air speed, heat dissipation can be improved by convection, a measure that is particularly beneficial for cattle in hot weather (see Serviento, 2022).

## Effective temperature

Effective temperature is used to analyse thermal comfort. The effective temperature (ET) felt by an organism can be established for the meteorological parameters of air temperature, relative humidity and wind speed (see Blazejczyk et al., 2012).

## Evaporation

Evaporation converts water from a liquid phase to a gaseous phase. This process allows an animal's excess body heat to dissipate. It occurs mainly through perspiration through the skin and, to a lesser extent, evaporation from the respiratory tract.

## Heat Load Index (HLI)

The HLI is an indicator designed to estimate an animal's degree of discomfort as a function of relative humidity, wind speed and solar radiation. It is calculated using two formulas, depending on the ambient temperature (AT).

When AT < 25°C: **HLI = 10.66 + (0.28 x RH) + (1.3 x BGT) - WS**, where AT is the ambient temperature (in °C), RH is the relative humidity (in %), BGT is the Black Globe Temperature (temperature measured in °C using a sensor contained in a black globe) and WS is the wind speed (in m/s).

When AT > 25°C: **HLI = 8.62 + (0.38 × RH) + (1.55 × BGT) - (0.5 × WS) + e (2.4 - WS)**, where AT is the ambient temperature (in °C), RH is the relative humidity (in %), BGT is the Black Globe Temperature (temperature measured in °C using a sensor contained in a black globe) and WS is the wind speed (in m/s).

## Heat stress

The animal experiences stress and/or negative affective states such as discomfort and/or distress when exposed to high effective temperature (EFSA, 2022a).

## Latent heat loss

Type of heat loss involved in thermolysis and characterised by a phase change, e.g. evaporation. Such forms of heat loss are induced to a greater extent when the outside temperature exceeds 30°C and sensible heat loss is reduced.

## Lower critical temperature (LCT)

Ambient temperature below which an animal must increase its metabolic heat production to prevent its body temperature falling below the normal range for the species.

## Panting

Breathing in short gasps carried out with the mouth open (Bracke et al., 2020). The first phase of panting is characterised by rapid, shallow breathing known as thermal polypnoea (increase in respiratory rate and decrease in amplitude and volume). This is followed by a second phase of slower, deeper breathing known as thermal hyperpnoea (increase in amplitude and volume), characterised by an increase in the alveolar ventilation rate (Hales & Webster, 1967). Panting is considered to be a physical sign of heat stress.

### Perceived temperature

The effective temperature as perceived by animals, which is also influenced by their endogenous characteristics.

### Radiation

(Long-wave, or terrestrial) radiation transfers heat through the emission of electromagnetic waves, enabling animals to exchange heat with their environments without direct contact with a solid object. Heat is transferred from warmer objects to cooler objects (including the animal's body).

### Relative humidity

The water vapour content (or saturation) of the air at a given temperature as a percentage of the maximum amount of water vapour that the air could hold at that temperature.

### Respiratory rate (RR)

This is the rate at which breathing occurs. It is assessed by the number of breaths per minute and is generally measured by counting flank movements based on direct observation (movements per minute). An animal's respiratory rate increases as a way of regulating body temperature (EURCAW Pigs, 2020). Thermal stress leads to an increase in RR to the point of panting.

### Road transport vehicle

Means of wheeled transport that is propelled (lorry) or towed (trailer). The characteristics of transport vehicles vary greatly depending on the transporter and the country. Such vehicles may have 1 to 5 decks, each of which may be divided into 2 to 4 compartments. According to EC regulation 1/2005 (EC Council, 2004), transport vehicles fall under two types of transporter authorisation: Type 1 (duration < 8 hours) and Type 2 (duration ≥ 8 hours). In addition to the vehicular features required for both lengths of journey (weather protection, non-slip flooring surface, appropriate loading and unloading equipment, etc.), vehicles for Type 2 authorisation must be equipped with a properly insulated light-colour roof, a specified water supply system, an active ventilation system, a temperature control system and a warning system to alert the driver if maximum or minimum temperature limits are reached. For journeys lasting 8 hours or more, animals of all ages must also be provided with appropriate bedding.

### Sensible heat loss

Type of heat loss involved in thermolysis and characterised by a change in a substance's temperature, e.g. radiation, conduction and convection. It is far harder for sensible heat loss to occur when the temperature gradient between an animal and its environment is weak.

## Solar radiation

Thermal radiation emitted by the sun with a high concentration of energy in the visible spectral region (350-750 nm) (Causone et al., 2010).

## Stress

Stress, including that experienced by animals, refers to the presence of negative affective states. These states occur when an animal feels threatened, whether the threat is real or not. The animal adapts to such a threat through its behaviour, exhibiting fight or flight reactions if it is afraid, for example, and through its physiology, in the form of an increased heart rate and the secretion of certain hormones to enable the expenditure of physical effort, for example.

## Temperature-Humidity Index (THI)

The THI is an indicator designed to estimate an animal's degree of discomfort as a function of ambient temperature and relative humidity. Several formulas are available to calculate THI. The IDELE (French Livestock Institute) uses the following formula, which was defined by the USA National Research Council in 1971: **THI = 0.8 x AT + (RH/100) x (AT - 14.4) + 46.4**, where AT is the ambient temperature (in °C) and RH is the relative humidity (in %).

## Thermal comfort zone (TCZ)

The thermal comfort zone corresponds to the temperature range that is most comfortable for an animal. It represents an individual's preferred thermal environment, requiring minimal metabolic and physiological thermoregulatory efforts (Silanikove, 2000). It is sometimes referred to as the "safe zone" (EFSA, 2022c).

## Thermal stress

The animal experiences heat or cold stress (see definitions). Thermal stress occurs in a situation where an animal’s physiological and behavioural heat dissipation mechanisms are no longer able to maintain the balance between metabolic heat loss and production.

## Thermogenesis

The process by which an organism produces heat. It is a by-product of an animal's metabolic activity. One way of categorising it is to divide it into basal thermogenesis (the minimum rate of heat production recorded in an animal at rest, fasting and under conditions of thermal neutrality) and the heat produced by muscular activity (Guingal, 2018).

## Thermolysis

Thermolysis is the process by which an organism loses heat. The heat loss can be latent or sensible.

## Thermoneutral zone

The thermoneutral zone marks the range of ambient temperatures within which metabolic rate and heat production of a homeothermic individual remain fairly minimal and stable independently of the ambient temperature. The zone is bounded by the lower critical temperature and the upper critical temperature (Bracke et al., 2020).

## Thermoregulation

An adaptive function by which an animal balances its heat production and loss through biochemical, physiological, morphological and/or behavioural adjustments to ensure that a stable internal temperature is maintained independently of external temperature (homeothermy).

## Upper critical temperature (UCT)

Ambient temperature above which an animal must increase its heat loss and/or decrease its heat production to prevent its body temperature rising above the normal range for the species.

# Abbreviations

**AT**

Ambient temperature

**FRCAW**

French Reference Centre for Animal Welfare (CNR BEA in French)

**HLI**

Heat Load Index

**LCT**

Lower critical temperature

**TCZ**

Thermal comfort zone

**THI**

Temperature-humidity index

**TNZ**

Thermoneutral zone

**UCT**

Upper critical temperature

# Figures and Text Boxes

## Figures



## Text Boxes

# 1 Method

This document summarises the information on thermal stress contained in the EFSA Opinion (2022b) on the welfare of cattle during transport. A certain amount of further research of the literature was carried out in order to provide, in particular, a description of the thermoregulatory mechanisms found in cattle. In line with the purposes of the original French expertise, including readability, not all references to the EFSA Opinion or its sources were flagged. References to additional materials not mentioned by the EFSA report were, however, included. The English-language version of this report therefore reflects these choices. As in the original report, the FRCAW's own contributions are shown in blue in the text other than in the glossary. The content of the English-language version of the glossary is based on the FRCAW's own definitions and cited sources, but has been adapted where appropriate to suit the requirements of an English-speaking audience.

# 2 The physiological and behavioural mechanisms of temperature regulation in cattle

Cattle are homeothermic animals. They thus have the ability to maintain a constant body temperature (with a rectal temperature of 38.0 - 39.3°C for dairy cows, and of 36.7°C - 39.1°C for beef cows (MSD Veterinary Manual, n.d.)) within a particular range of microclimatic conditions, by adjusting their behaviours and metabolism (Chaire BEA; (Islam et al., 2021). Within the TNZ, little adjustment is required for cattle to maintain homeothermy. This is because, within the TNZ, an animal's metabolic heat production (which is naturally generated by the basal metabolic activity of each individual) is balanced against its passive heat loss (sensible loss) to the environment through radiation, conduction and convection. Outside the TNZ, regulation of body temperature in cattle calls for the physiological and behavioural mechanisms described below, with numerous consequences for the behaviour, welfare, health and metabolism of individuals.

## 2.1 Exposure to low temperatures

In response to cold, a number mechanisms are activated in cattle to generate metabolic heat while limiting heat loss (Sutherland et al., 2013). When the temperature falls, metabolic heat production in cattle can be increased by shivering, i.e., involuntary muscle contractions (Roland et al., 2016). In young calves, the oxidation of brown adipose tissue is also a source of heat (Alexander et al., 1975; Young, 1981). Heat loss, particularly through convection, can be limited by vasoconstriction (the reduction of blood flow to the extremities) and piloerection (the raising of the hair in an animal's coat into an upright position to create a thicker insulating layer of air), (Roland et al., 2016). In calves, the first physiological changes in response to cold are observed at around 19°C with the appearance of piloerection, vasoconstriction and then, from 10°C, shivering (Gonzalez-Jimenez & Blaxter, 1962). Particular behaviours in response to the cold can also be observed, such as searching for shelter as a protection from the elements and huddling together, where close physical contact between individual animals reduces the surface area of the body exposed to the cold and body heat is conserved within the group (Da Silva, 2012; Khalifa, 2003). An increase in food consumption to meet the increased need for energy may also be observed (Roland et al., 2016). In the most extreme cases (see*Figure 1*), exposure to cold can lead to the development of subcutaneous oedema, haemorrhage or frostbite (Olson et al., 1980; Rawson et al., 1989) and to animal deaths - particularly in calves under 4 weeks old.

## 2.2 Exposure to high temperatures

In response to heat, various mechanisms are activated to dissipate the heat and, if possible, avoid hyperthermia. In particular, latent heat loss (through evaporation) gradually increases when temperatures rise above 25°C. In cattle, the main mechanisms for dissipating heat are transpiration, increased respiratory rate and licking (Kadzere et al., 2002). In addition to physiological changes, behavioural modifications can also be noted in response to high temperatures. For example, cattle may increase their water intake to compensate for water losses due to evaporation, and may reduce their dry matter intake and time spent ruminating to limit metabolic heat production (Dovolou et al., 2023). At temperatures above 25°C, cattle also actively seek shade in order to alleviate the increase in heat caused by radiation (Schütz et al., 2008). Furthermore, as the temperature rises, cattle spend less time lying down. By remaining upright, they can increase the body surface area available for heat dissipation through convection and evaporation (Cook et al., 2007). In the most extreme cases (see*Figure 1*), exposure to heat can lead to the severe dehydration of individual animals who do not consume enough water, which can result in death.

## 2.3 The thermoneutral zone

**Calculation of the thermoneutral zone (TNZ) (***Figure 1***)**: To date, only an approximate estimate of the TNZ for cattle is possible. Difficulties in accurately estimating the TNZ are caused by, among other things: 1) the fact that the TNZ is dependent on numerous factors that are both endogenous (e.g. an individual animal's age) and exogenous (e.g. relative humidity); 2) the lack of standardisation of thermal indices (such as the temperature-humidity index) and the absence of a clear consensus on the thresholds above which animals enter a state of thermal stress; and 3) the lack of specific investigation of cold tolerance in cattle. Based on the current state of scientific knowledge (summarised above), the EFSA has nevertheless set the UCT for calves and adult cattle at around 25°C. LCT limits are less clearly defined. No value is proposed for the LCT in the EFSA Opinion for adult cattle, while other sources put it at around 5°C (European Commission, 2019). The LCT for calves would appear to range between 5 and 15°C, and greater sensitivity to cold is identified in unweaned calves (Scanes, 2011).

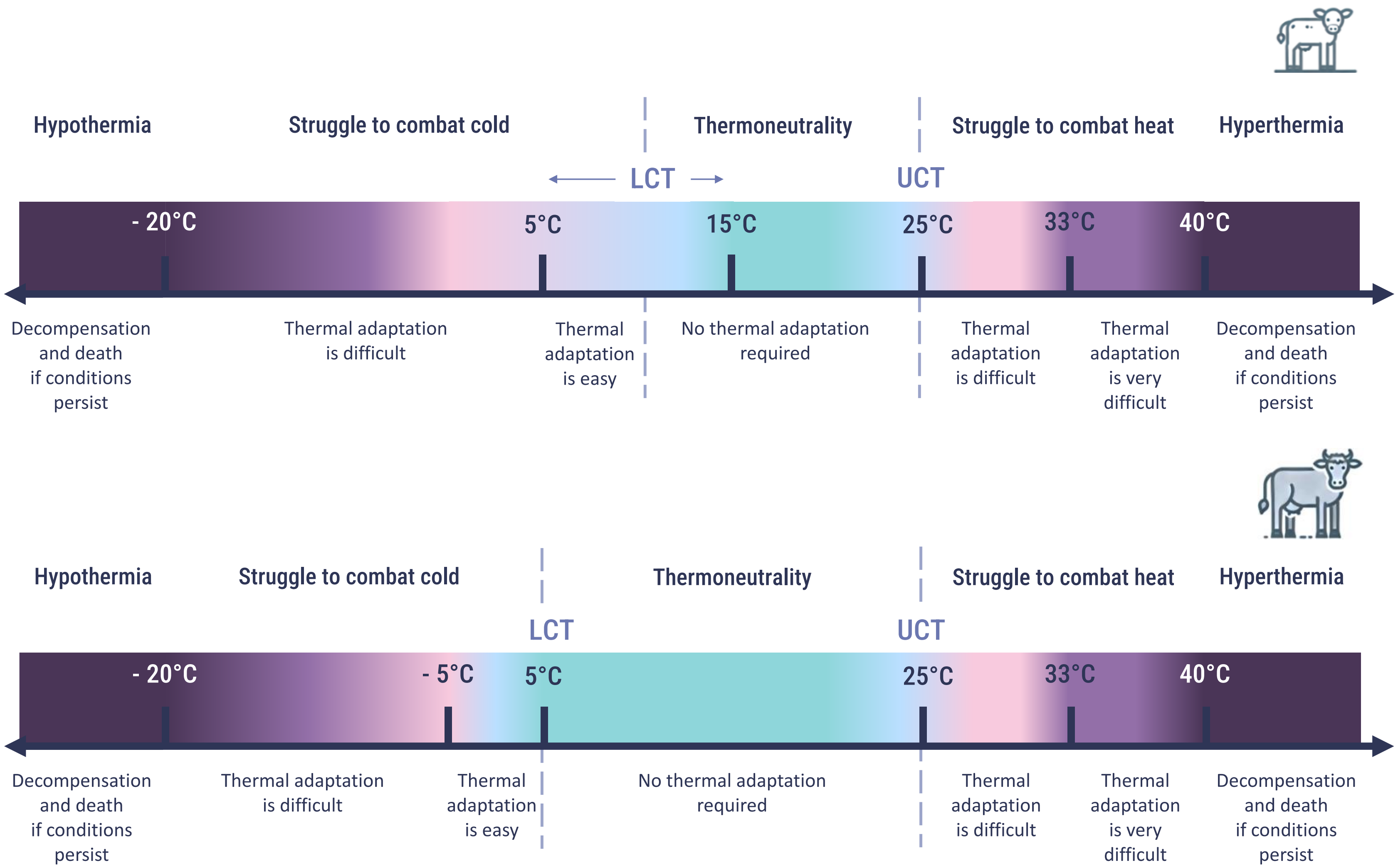


*Figure 1. Diagram of cattle adaptation mechanisms (calves and adult cattle) as a function of ambient temperature - (adapted from (Guingal, 2018) ). LCT: Lower Critical Temperature (5°C in adult cattle, range of 5-15°C for calves), UCT: Upper Critical Temperature (25°C for all cattle). The indicative temperatures shown in the graduated images reflect the information provided in the sources cited above. However, not all are universally accepted due to the lack of clearly-established thresholds.*

By way of illustration, during the three meteorological winter months of 2023-2024, the average minimum temperatures in France remained consistently below the upper estimated LCT limit for calves (15°C), although they were mostly above seasonal norms (*Figure 2*). Meanwhile, the minimum average temperatures recorded for the same period in France were higher than the LCT for adult cattle for around 47 days, or 52% of the 2023-2024 winter months (*Figure 2).* It should be noted that in France the winter of 2023-2024 was the 3rd mildest since 1900 (Météo France, 2024a). In the summer of 2024, high temperatures began from the end of July, with an initial short, intense heatwave followed by a second, longer but less intense period of heat. The south-eastern part of the country, and the Mediterranean region in particular, experienced sustained heat throughout the summer, with very hot night-time temperatures (Météo France, 2024b). Average daily maximum temperatures across France only fell below the UCT for cattle on around 30 days, together representing a third of the summer of 2024 *Figure 3*).

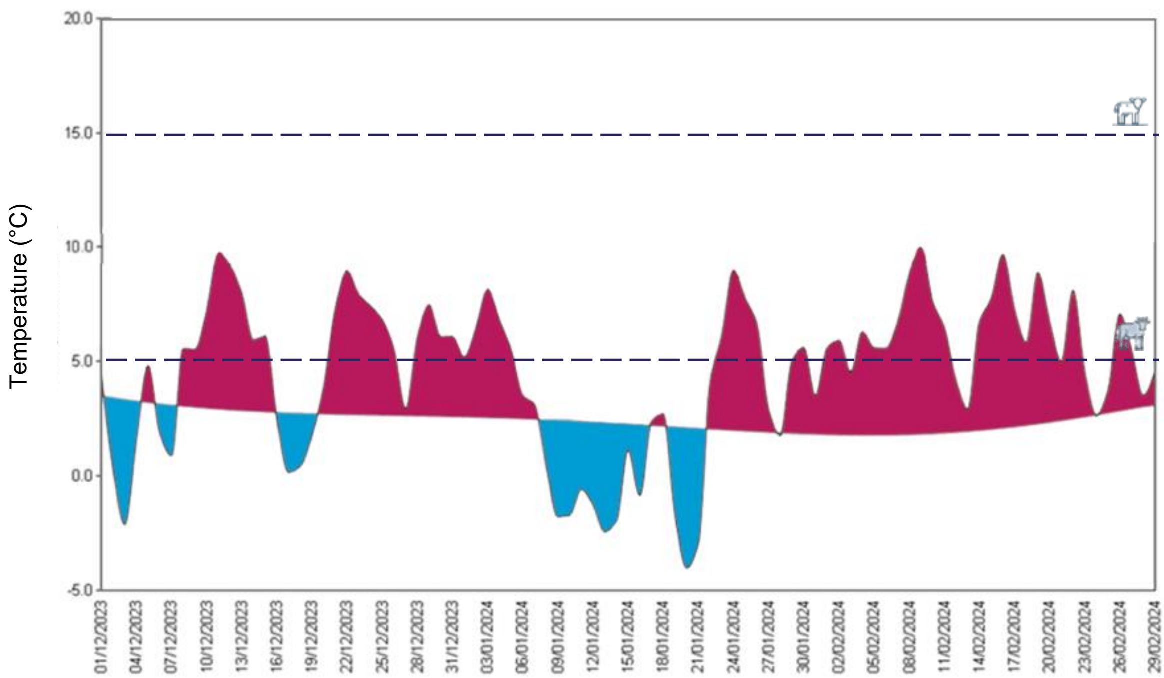


***Figure 2. Profile of fluctuations in the daily minimum temperatures in France for 1 December 2023 to 29 February 2024, compared with the historical daily average from 1991-2020, (temperature profile generated from averaged 24h data from 30 weather stations in mainland France). Dashed lines show upper estimated LCT for calves (15°C) and LCT for adult cattle (5°C) respectively.*** Adapted from ***(Météo France, 2024a)***

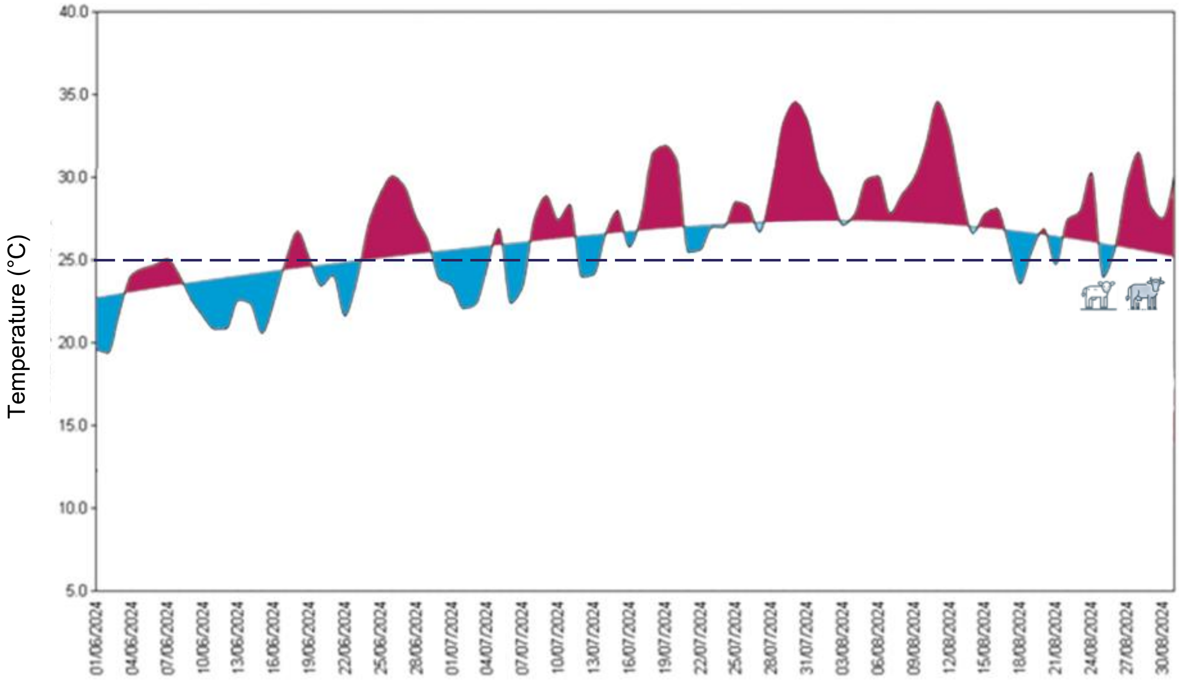


*Figure 3. Profile of fluctuations in the daily maximum temperatures in France for 1 June 2024 to 31 August 2024, compared with the historical daily average from 1991-2020 (temperature profile generated from averaged 24h data from 30 weather stations in mainland France). Dashed line represents the UCT for calves and adult cattle (25°C). Adapted from (Météo France, 2024b)*

# 3 Factors affecting the thermal comfort of cattle

The factors affecting perceived temperature (PT) for cattle (and, consequently, the TNZ threshold values that apply to each individual animal) can be divided into two main categories: endogenous factors and exogenous factors.

## 3.1 Endogenous factors

Endogenous factors (i.e., factors inherent to the animal) that affect perceived temperature (PT) in cattle include, in particular:

+ **Productiveness:** High-producing animals are generally more sensitive to heat than less productive cows, since they generate more metabolic heat. For example, the

UCT is estimated to be 20-24°C for Holstein cows, but over 32°C for indigenous breeds of zebu (found in the French overseas regions, for example).

+ **Body condition:** Because of their limited fat reserves, the body condition of many cull cows is poor, and this can exacerbate their discomfort in low temperatures. Conversely, cows with greater reserves of fat may feel less discomfort at low temperatures.

+ **Gestation stage:** A cow's sensitivity to heat increases during gestation.

+ **Age:** Young calves may have trouble in thermoregulating properly, mainly because of their lower fat reserves. The EFSA makes no mention of any differences in thermoregulatory capacity between cattle in other age categories. This is a potential area for further study.

+ **Temperatures previously experienced on farm:** Cows are sensitive to cold when exposed to temperatures that are lower than those to which they have been acclimatised during housing (i.e., on the farm).

+ **State of health:** Cull cows suffering from lameness[1], mastitis and reproductive diseases may have greater difficulty in thermoregulating during transport. Similarly, sick calves are more vulnerable to cold stress, as animals that are suffering tend to produce less metabolic heat. Calves suffering from pneumonia may also be more sensitive to heat due to their reduced lung capacity.

+ **Agitation level:** The EFSA lists agitation level as one of the endogenous factors influencing the TNZ. Animals that are agitated and/or physically exerting themselves produce more metabolic heat and are thus more sensitive to heat stress. It should therefore be noted that, in periods of intense heat, the loading/unloading stages in particular carry an increased risk of heat stress (Brown-Brandl, 2013).

+ **Hair colour:** Coat colour can also influence the TNZ in cattle. In particular, several studies have shown that the body temperature of black cows rises faster than that of red or white cows. It also takes longer for black cows to dissipate heat (Anzures-Olvera et al., 2019; Holliday et al., 2023).

+ **Breed:** Dairy breeds are generally more sensitive to heat than suckler breeds. This is associated in particular with a combination of the factors listed above (productiveness, body condition, coat characteristics, etc.). No breed-specific effect on the TNZ has yet been demonstrated.

[1] It should be noted that it is not permitted for severely lame cows, i.e., cows unable to move without assistance or additional pain, to be transported.

## 3.2 Exogenous factors

Other than ambient temperature, a number of exogenous factors affect the perceived temperature of cattle during transport. Ideally, each of these factors should be considered when assessing transport conditions for animals. Exogenous factors include:

- **Humidity:** The risk of heat stress increases significantly as air humidity rises. High air saturation levels reduce the effectiveness of evaporation (achieved by sweating, licking and panting), which is the main means of thermoregulation for cattle when the ambient temperature is high. Put differently, humidity produces a lower UCT by reducing the effectiveness of the heat loss mechanisms used by cattle. The combined effect of temperature and relative humidity on the risk of heat stress can be assessed using the THI (see *Box 1*).

**Box 1. Temperature-Humidity Index (THI): calculation method and implications for cattle**

The THI is an indicator designed to calculate an animal's degree of discomfort as a function of ambient temperature and relative humidity. Several different formulae are available to calculate THI. The IDELE (French Livestock Institute) uses the formula developed by the National Research Council (1971):
**THI = 0.8 x AT + (RH/100) x (AT - 14.4) + 46.4,** where AT is the ambient temperature (in °C) and RH is the relative humidity (in %).

The following THI thresholds can be referred to for **dairy cows** (Broucek et al., 2009; Brown-Brandl et al., 2003; Collier & Collier, 2012):

- **THI < 68** (high production cows) or **< 72** (standard production cows): no heat stress
- **68 ≤ THI < 72**: mild heat stress
- **72 ≤ THI < 78**: moderate heat stress
- **78 ≤ THI < 82**: severe heat stress
- **THI ≥ 82**: extreme heat stress

Thus, when the AT is 30°C:

- if the relative humidity is **5%**, dairy cows could experience **mild** heat stress (THI = 71.18)
- if the relative humidity is **70%**, dairy cows could experience **severe** heat stress (THI = 81.32).

For **suckler cattle**, the following THI thresholds can be referred to (Gaughan et al., 2008):

- **THI < 70**: little or no heat stress
- **70 ≤ THI < 77**: moderate heat stress
- **77 ≤ THI < 85**: severe heat stress
- **THI ≥ 85**: extreme heat stress

+ Solar radiation: The sun's rays on the roof and sides of a truck can increase the temperature inside a vehicle, thereby increasing the risk of heat stress for the animals it contains. It is possible to calculate the combined effects of temperature, solar radiation, relative humidity and wind speed on the risk of heat stress using the HLI (*Box 2.*

**Box 2. Heat Load Index (HLI): calculation method and implications for cattle (Gaughan et al., 2008)**

The HLI is an indicator designed to calculate an animal's degree of discomfort by taking into account relative air humidity, wind speed and solar radiation. It is calculated using two equations, depending on the ambient temperature.

When AT < 25°C, the HLI is calculated as follows:

$HLI = 10.66 + (0.28 \times RH) + (1.3 \times BGT) - WS$ where RH is the relative humidity (in %), BGT is the Black Globe Temperature (temperature measured inside a device called a "black globe", in °C) and WS is the wind speed (in m/s).

When AT > 25°C, the HLI is calculated as follows:

$HLI = 8.62 + (0.38 \times RH) + (1.55 \times BGT) - (0.5 \times WS) + e^{(2.4 - WS)}$ where AT is the ambient temperature (in °C) and RH is the relative humidity (in %).

The following HLI thresholds can be referred to for **cattle:**

- **HLI < 70**: no heat stress
- **70 ≤ HLI < 77**: mild heat stress
- **77 ≤ HLI < 86**: moderate heat stress
- **86 ≤ HLI < 96**: severe heat stress
- **HLI ≥ 96**: extreme heat stress

+ Water and snow ingress: Water and snow entering the lorry are risk factors for cold stress (European Commission, 2019).

+ Air circulation inside the lorry: The circulation of air around the heads and bodies of the animals facilitates the dispersion of body heat and stabilises gas levels, thereby lowering the perceived temperature of the animals (*Box 2.*). It does so by replacing the warm, humid air produced by the animals with cooler air from outside. Several interdependent factors influence the efficiency of air circulation inside the vehicle, including ***ventilation type and speed of travel.*** Passive ventilation relies on two main air flows: 1) a horizontal flow linked to the movement of the vehicle and the difference in air pressure that is created between the front and rear of the vehicle (producing a continuous flow of air from the rear to the front of the lorry) and 2) a vertical flow of air, or chimney effect, produced by differences in temperature (warm air is drawn upwards and is replaced by cold air). When a lorry slows to a halt, it no longer creates the difference in pressure required for fresh air to enter and warm air to leave, reducing the effectiveness of passive ventilation. The risk of heat stress due to the build-up of heat and humidity therefore increases - particularly for animals occupying the top deck of the vehicle (where warm air collects without being effectively replaced by cooler air). Mechanical ventilation is often more effective in creating an air flow than passive ventilation, as fans are activated to operate at a suitable rate to push the air around. However, in low temperatures, too much ventilation can lead to cold stress (European Commission, 2019).

+ Location of the animals in the lorry: The majority of transport lorries used in the European Union have two decks. As a consequence of the patterns of air circulation described above, in hot periods, animals located at the front and top of the vehicle are more at risk of heat stress than those elsewhere. This is because the hottest locations are at the front and top of the lorry, while the coldest locations are found on the lower deck at the rear. During cold spells, when the outside temperature is at around 0°C, a recent study recorded a significantly lower temperature during transport on the upper deck (15.2°C) than on the lower deck (16.9°C) (Pasquale et al., 2024). The areas nearest to inlets in the exterior skin of the lorry are also colder as the result of air circulation. Thus, in winter, cattle placed at the top of a lorry, particularly those near the ventilation inlets, are more exposed to cold stress.
+ Loading density: In hot weather, the risk of heat stress is increased when animals are transported at high loading densities, as there are more individuals producing metabolic heat and moisture.
+ Vertical space: Animals may find it difficult to thermoregulate properly when there is limited space above them, as this reduces air ventilation within the vehicle.
+ Water consumption: Being deprived of water before and during transport increases an animal's risk of heat stress, particularly at high temperatures, since sweating and panting (as well as the evacuation of urine and faeces during the journey) result in a significant loss of water that cannot be replaced. If cattle do not drink during a journey, thirst and a state of dehydration can set in (associated with significant weight loss), their electrolyte balance is disturbed, and their kidney and liver functions are impacted. Physiological changes that were probably linked to water deprivation have been observed after 9 hours of transport. Water consumption in cattle depends on a number of factors such as the availability, accessibility and number of drinkers, and the familiarity of individual animals with the devices provided. A lack or inadequate provision of watering points in the loading area and lorry, difficulty in accessing drinkers, and/or a lack of familiarity in individual animals with such devices are therefore factors likely to encourage heat stress. However, it should be noted that the consumption of water by cattle is not guaranteed by the presence of drinkers in a lorry. Indeed, some studies suggest that cattle drink less during transport than on farm, even if drinkers are available.
+ Waiting times: Any delay in loading and unloading operations (due, for example, to poor organisation or untrained staff) exposes animals to a greater risk of heat stress, particularly when the weather is hot and humid. When waiting times increase, animals are confined in the lorry for longer periods, often with limited ventilation.

This creates the conditions for heat to build up inside the vehicle, producing an environment likely to provoke heat stress.

+ Journey duration: To date, few studies have examined the effect of journey duration on thermal stress in cattle, and most of those available were conducted under conditions similar to those in the TNZ. Even under these conditions, it was reported that longer journey times would expose cattle to an accumulation of factors likely to increase the risk of thermal stress - with, for example, a greater risk that cattle would be exposed to excessive temperatures and to high humidity during the day and would risk extended periods of water and feed deprivation.

+ Route design: Depending on the marketing route taken, the impact of the factors listed above on the risk of thermal stress experienced by cattle will vary. For example, cull cows sent to slaughter via auction markets are generally transported over longer distances with very limited access to feed and water. The body weight and condition of the cows can then deteriorate, with signs of dehydration, all of which increases the risk of thermal stress.

# 4 Levers for action to improve the thermal comfort of cattle during transport by lorry

## 4.1 Levers for action in the event of high temperatures

The following measures can be considered to improve the thermal comfort of cattle and prevent temperatures in the vehicle from exceeding 25°C[2]. As a point of information, the European Commission recommends that cattle should not be transported when weather forecasts predict outside temperatures exceeding 21°C for lactating cows, and 25°C for calves and other adult cattle over all or part of the planned journey (European Commission, 2019).

### 4.1.1 Levers for action during loading and unloading

Certain precautionary measures must be applied from the loading stage onwards, to limit the risk that the animals will develop heat stress once they have been transported on the lorry.

**Loading conditions:**

- **Time of loading:** Loading should be carried out when temperatures are at their lowest, i.e., late evening, early morning or at night if necessary.
- **Layout of holding facilities:** The holding area should be equipped with 1) a shaded shelter to reduce the animals' direct exposure to sunlight and 2) water points to prevent or *at least* limit dehydration during transport. It is also beneficial for the animals to ensure that this area is well ventilated. Misting systems, sprinklers or showers can also be installed to cool the animals. Such systems should, however, be used in conjunction with ventilation fans, as their use without fans increases humidity and hence the vulnerability of the animals to heat. This is particularly important when the surrounding air is also humid, limiting the possibility for the animal to dissipate heat through evaporation. It should be noted that little or no research has been carried out into the risks associated with the transport of wet animals.

[2] The measures listed in this section are not ranked in order of importance.

## Stress management for cattle:

- **Cattle handling:** The stress associated with handling - and the resulting agitation of each animal - can be reduced by applying good handling practices for cattle (see Section 3.3, Handling during Loading, of the Guide to Good Practice for the Transport of Cattle, European Commission, 2018).
- **Design of facilities:** Facilities must be correctly designed and maintained to ensure the safety of cattle and to avoid increased distress, which brings a greater risk of heat stress (for example, the loading route should be suitable for cattle, the gradient of the access ramp to the lorry should be 20° or less and have a non-slip surface).

## Organisation of transport operations:

- **Planning operations:** Cattle loading and unloading operations must be carefully planned to keep transport times to a minimum and ensure that the animals are transported under optimum conditions[3]. For example, filling the water tank to supply the troughs on board the lorry should not be forgotten when preparing for short journeys [4] (European Commission, 2019).

- **Coordination between operators:** Staff at the various destination locations must be informed of the animals' arrival time so that they can ensure that the facilities are ready, thus avoiding any delays that could affect the condition of the animals negatively.

## Management of special cases:

- **Animals showing signs of dehydration:** Animals showing signs of dehydration (persistent skin tenting, enophthalmos, dry mucous membranes, increased heart rate and respiratory rate) while awaiting loading should not be loaded. They must be immediately removed from the loading area and left in a cool location with access to water.
- **Calf feeding:** As the exact requirements for feeding unweaned calves during transport are unknown, calves need to have consumed milk (or milk replacer) before being loaded onto the lorry in order to prevent or mitigate energy depletion and/or hypoglycaemia during transport. They should be fed around four hours before loading to ensure correct digestion and limit the risk of diarrhoea - and hence dehydration - during the journey. If loaded immediately after a meal, the stress experienced prevents the formation of a casein clot in a calf's abomasum, increasing the risk of digestive problems. It should be noted that the transport of calves in hot weather calls for special preparations to be made by the farmer to enable the calves can be fed four hours before night-time or early-morning loading. To promote digestion, calves in the holding area must also be given sufficient space to lie down and rest before loading.

[3] Any adjustments may require changes to the working conditions of the staff involved.
[4] This is mandatory for long journeys.

### 4.1.2 Levers for action during transport in the lorry

#### Organisation of transport operations:

+ **Time of transport:** Cattle should be transported during the coolest periods of the day (including the night). As a reminder, the EFSA recommends that cattle should not be transported when temperatures in the lorry exceed 25°C (see 'Monitoring heat stress', below, on how such temperatures are measured).

+ **Length of breaks:** Breaks in a journey should ideally be as short as possible (although they should comply with the minimum stopping times for drivers), particularly where there is no air conditioning in the lorries. In hot weather, preference should be given to short journeys that require no breaks (for the driver or the animals). For journeys where the animals need to be unloaded, sufficient time (*a priori* longer than 12 hours) should be allowed between unloading and loading so that the cattle can drink, rest and feed.

#### Lorry design:

+ **Construction materials:** The EFSA recommends that the roofs and sides of vehicles be fitted with insulation and/or radiation-reflective materials on the outside to limit the rise in temperature inside the vehicle due to solar radiation.

+ **Ventilation system**: The use of mechanical ventilation, particularly when the truck is stationary, is strongly recommended to limit the risk of heat stress. It should be noted, however, that in hot, humid weather, even mechanical ventilation may not be enough to maintain a comfortable microclimate for the animals - temperatures inside the truck always remain higher than outside temperatures in the absence of cooling systems. For trucks with passive ventilation only, the total ventilation surface should be more than 40% of the total area of the container sides and should not have aerodynamic air foils that restrict airflow into the trailer (European Commission, 2019).

+ **Loading density:** A reduction in cattle loading density would also help prevent heat stress, particularly if the vehicle has no mechanical ventilation. A 20% reduction in loading density has been proposed in relation to current regulatory densities (Council Regulation (EC) No 1/2005) but the effectiveness of such a measure has not been scientifically proven. Any change in loading density should also take into account the space required to install drinking troughs in the lorries, which should be sufficient to allow all the cattle to drink simultaneously.

+ **Deck height:** Deck heights within the truck must be sufficient to ensure effective ventilation. On days when the temperature does not exceed 20°C, a deck height of wither height x 1.17 + 20 cm (for the tallest animal in the load) is suggested for cattle to ensure good air circulation around the animals. At warmer temperatures, more height may be required in lorries without mechanical ventilation to encourage greater passive ventilation and thus lower the effective temperature. The optimum heights for both adult cattle and calves under all climatic conditions should nevertheless be studied further.

**Monitoring heat stress:**

+ **Position of the sensors:** To monitor the thermal environment during transport, vehicles should be equipped with sensors recording microclimatic conditions (e.g. THI and HLI, see *Box 1* and *Box 2*). They should be as close as possible to the position of the animals in the vehicle and at several locations to include hot as well as colder spots. It is also recommended that at least two sensors be installed on each deck of the lorry (European Commission, 2019).
+ **Parameters for measurement:** To best assess the animals' microclimatic environments, the sensors that are fitted should measure, *a minima*, a combination of temperature and humidity parameters.
+ **Sensor reliability:** The sensors must be calibrated and checked regularly to ensure that they are operating reliably.
+ **Readings from the sensors:** The vehicle driver must be able to monitor the microclimate (temperature and humidity *a minima*) inside the vehicle and adjust ventilation quickly and easily when temperatures approach the TNZ thresholds. If a break is necessary for this, a shady spot should be chosen, and the duration of the break should be kept to a minimum.

### 4.1.3 Levers for action during journey breaks

During the journey, it may be necessary to allow the animals one break or more to rest, drink and feed. Two types of journey break can be taken: directly **on board a stationary vehicle**, or by unloading the animals at a **checkpoint** or similar. To avoid negative consequences for cattle, the EFSA recommends that journeys not requiring breaks be chosen in preference to those that do, particularly in very hot weather, if the vehicle is not equipped with air conditioning. When a journey break is needed for the animals, the EFSA recommends that animals should be unloaded in preference to being left on board the lorry, and that breaks should be sufficiently long to allow the animals to drink, rest and feed. In all cases, the measures outlined below should be considered if a break is taken in hot weather.

**On board the lorry:**

+ **Ventilation:** If the truck is not equipped with a mechanical ventilation system, it is crucial to ensure that the ventilation spaces are large enough and well designed to avoid heat build-up when the vehicle is stationary. It is also essential to avoid stopping the vehicle in locations where ventilation is restricted. Activating fans on board a stationary vehicle has been shown to lower the internal temperature by 2-3°C when the outside temperature is 30°C (Pasquale et al., 2024).

+ **Access to water:** The EFSA recommends that trucks be equipped with sufficient drinking troughs to allow all cattle to drink simultaneously. It should be noted that the provision of water in a stationary vehicle does not guarantee its consumption by individuals. Several studies that have examined the effect of a mid-journey break to provide food, water and rest within the vehicle have reported limited success in improving individual welfare. Nevertheless, it is essential that animals have access to water to refresh themselves if they wish.
+ **Length of breaks:** The optimum length of breaks on board the truck to allow the animals to eat, drink and rest is not known. The literature suggests that one-hour breaks on board the truck are not sufficient to allow all the animals to eat, drink and rest. It should be noted that the total journey duration is increased by longer breaks, imposing further constraints on animal welfare during transport. Ensuring the welfare of the animals therefore involves a compromise between the need for breaks to be effective and increased total journey times before unloading at the final destination.
+ **Parking:** The lorry should be parked in the shade, particularly if it has no air conditioning, to prevent the sun's rays from increasing the effective temperature.

## Checkpoints:

+ **Access to water:** Easy and immediate access to water is necessary on arrival at a checkpoint. Water must be provided in sufficient quantities and in facilities adapted to the particular needs of the animals - all the more so if access to water during the journey has been limited. The amount of water required by adult and developing cattle to maintain homeostasis is high. These requirements vary between 27 and 66 L/day for young cattle and can be as much as 100 L/day for high-producing dairy cows. At checkpoints, EFSA recommends the provision of suitable drinking troughs, with a minimum flow rate of 12 L/min and a trough height of 0.5 m for young calves (50 kg) or 0.75 m for cattle weighing over 650 kg. One trough is required for every 10 cows, with at least two troughs per pen, spaced at least 60 cm apart.
+ **Length of breaks:** Breaks at control points must be long enough to allow each animal to eat, drink and rest. Currently, the literature provides no definitive conclusion as to their optimum duration.

## Management of special cases:

+ **Animals showing signs of heat stress:** If signs of heat stress are noted by the driver during a journey break, the animals concerned should be unloaded quickly and transferred to a shaded, ventilated area with a water supply. Animals can be cooled using misting systems, sprinklers or showers, which should be combined with good ventilation if relative humidity is high. If unloading is not immediately possible, the driver must ensure that the journey is completed as quickly as possible and should increase ventilation.

## 4.2 Levers for action in the event of low temperatures

The following measures can be considered to improve the thermal comfort of animals being transported by lorry, and prevent temperatures in the vehicle from falling below the LCT that applies to the animals involved. It should be noted that the levers for action described below appear in the EFSA opinion in relation to the thermal comfort of calves specifically. They also appear to the FRCAW to be of relevance for adult cattle. As a point of information, the European Commission recommends that cattle (calves and adults) should not be transported when weather forecasts predict outside temperatures below 5°C over all or part of the planned journey (European Commission, 2019).

### 4.2.1 Levers for action during transport by lorry

#### Supply of bedding:

+ **Type of bedding:** Suitable bedding materials help to reduce cold stress by reducing heat loss. Straw is considered the best option.
+ **Depth of bedding:** Where bedding is deep enough, it allows a calf to nest down and trap a boundary layer of warm air around itself - thus reducing its LCT. A minimum depth of 15 cm has been recommended. To benefit from this, calves must be able to lie down.
+ **Bedding condition:** When bedding is clean and dry, this helps to maintain its insulating function by preventing the spread of moisture.

#### Loading density:

Loading densities in a lorry influence the thermal comfort of calves by altering heat-production and humidity levels. Animals must have sufficient space to adopt postures that enable them to conserve more heat (to be able to lie down in particular) and to move away from the coldest areas. However, no study has yet provided detailed recommendations on the minimum space required to prevent cold stress in calves.

#### Protection from weather:

Protective tarpaulins can be used to protect animals from wind, rain and snow (European Commission, 2019). The degree to which windows and vents are opened or closed must be adjusted to suit weather conditions (European Commission, 2019) and it must be possible for opening and closing to be carried out both simply and quickly in the event of a sudden change in weather conditions.

**Water management:**

Exposure to cold can lead to dehydration in animals. Water pipes and troughs must therefore be prevented from freezing so that animals can drink while on board the lorry should they wish to. The use of heating devices or the addition of mixtures of glycerine and glucose to the water can prevent freezing (European Commission, 2019). An alternative option is to provide the animals with lukewarm, non-stagnant water. Indeed, during cold spells, cattle have been found to drink water more readily when it is lukewarm (Grossi et al., 2021; Petersen et al., 2016).

**Stationary vehicles:**

+ **Parking:** The lorry should be parked in an area sheltered from the wind (European Commission, 2019).
+ **Protection from weather:** protective materials (to prevent rain or wind ingress, see earlier paragraph specifically dealing with this) must be reinforced in a way that does not prevent adequate ventilation to be maintained (European Commission, 2019).

### 4.2.2 Levers for action during journey breaks

**Resource management:**

+ **Feed supply:** When cattle are exposed to low temperatures or wind (for example, when the vehicle is in motion), their feed requirements increase to provide the energy they need to maintain their body temperature. As no studies have so far been able to identify successful strategies to encourage cattle to eat while on a lorry, it is essential that they should have immediate access to sufficient food once unloaded. For information, the physiological changes associated with feelings of hunger may appear after 12 hours. If there is no *ad libitum* distribution of food during journey breaks, a sufficient number of feeders should be made available to reduce competition (the exact number remains to be established).
+ **Water supply:** Cattle should be supplied with water at the same time as feed.

# 5 Conclusions and future research

## 5.1 Report conclusions

When the weather forecast for all or part of a journey would prevent cattle from remaining within their thermoneutral zone while inside a vehicle, the decision should be taken for animals not to travel in order to reduce their risk of thermal stress. The EFSA does not specify a journey duration threshold below which it would be allowable to transport animals under sub-optimal conditions. Therefore, regardless of the journey duration, no cattle should be transported when temperatures in the lorry are likely to be above 25°C or below 5°C (or 15°C for calves). In hot weather, it is therefore preferable to arrange for journeys to be made early in the morning or during the night.

In order to monitor the climatic conditions within transporting vehicles, it is essential to install sensors that are able to measure the microclimate (recording, as a minimum, temperature, humidity and wind speed so that the effective temperature can be measured) at several strategic locations in the lorry (at least on each deck, close to vents, and at the front). The sensors should be connected to a built-in warning system in the driver's cab that would immediately notify the driver when conditions are approaching or exceed critical temperature thresholds. This system would enable drivers to take the preventive and corrective actions (see Section 4) needed to reduce the risk of thermal stress. It should be noted that the interactions between the possible levers identified in this report should be considered, so that their implementation can be as effective as possible (for example, increasing passive ventilation to reduce heat stress is of more use if a lorry has no dynamic ventilation system).

If no effective action is available or possible to implement within a reasonable time frame, then the animals should be unloaded as quickly as possible. This would, however, require the development of a network of facilities for transported animals.

For drivers to be able to implement the appropriate preventive and corrective measures and to detect the presence of thermal stress in the animals being transported, it is essential that they should be properly trained in good practice and in reading and interpreting thermal stress indicators in animals.

Last, only the thermoneutral zone of cattle has been considered in this report, for the sake of clarity and practicality. In its Opinion, though, the EFSA does stress that the thermal comfort of cattle is optimal when temperatures fall within their thermal comfort zone (TCZ). Accordingly, consideration of the TCZ in assessing transport conditions relating to the welfare of animals should still take precedence over that of the TNZ. This suggests that the limits of the TCZ in cattle need to be better defined, given how little they have been studied to date.

## 5.2 Future research required

Further research is needed to 1) improve understanding of the thermal comfort conditions for cattle (at all physiological stages) and 2) confirm and ensure that the preventive and corrective measures proposed are appropriate and optimal, establishing quantitative values to determine their effectiveness under transport conditions.

*Figure 4* provides a summary of research areas for further development and the actions needed to plug the gaps in current knowledge that would enable the risks of thermal stress for cattle during transport to be mitigated.

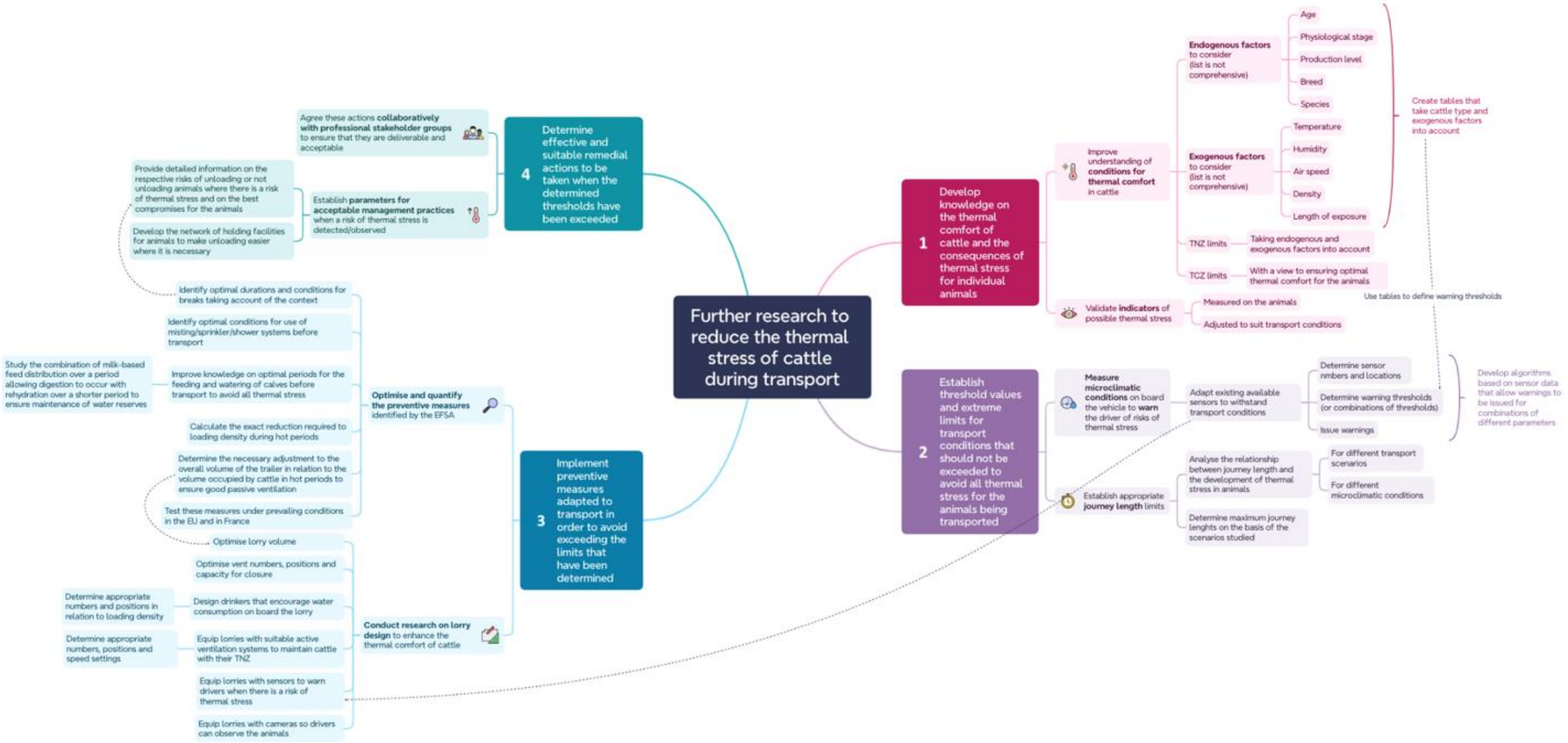


*Figure 4. Summary of key directions for research to reduce the risk of thermal stress in cattle during transport*

## 5.3 Further areas for improvement

There are at least two further general measures that were not addressed in the EFSA Opinion but that should also be considered in terms of their significant reduction of the stress placed on animals during transport. First, the slaughter (and rearing) of animals in **locations close to** their places of origin would reduce journey times and would facilitate the **transport of carcasses** rather than live animals wherever possible. Second, **exports of** live animals outside the European Union should only be approved if animal welfare is respected in line with the European regulations.

# Bibliography

*Alexander, G., Bennett, J. W., & Gemmell, R. T. (1975). Brown adipose tissue in the new-born calf (Bos taurus). The Journal of Physiology, 244(1), 223–234. https://doi.org/10.1113/jphysiol.1975.sp010793*

*Anzures-Olvera, F., Véliz, F. G., De Santiago, A., García, J. E., Mellado, J., Macías-Cruz, U., Avendaño-Reyes, L., & Mellado, M. (2019). The impact of hair coat color on physiological variables, reproductive performance and milk yield of Holstein cows in a hot environment. Journal of Thermal Biology, 81, 82–88. https://doi.org/10.1016/j.jtherbio.2019.02.020*

*Blazejczyk, K., Epstein, Y., Jendritzky, G., Staiger, H., & Tinz, B. (2012). Comparison of UTCI to selected thermal indices. International Journal of Biometeorology, 56(3), 515–535. https://doi.org/10.1007/s00484-011-0453-2*

*Bracke, M. B. M., Herskin, M. S., Marahrens, M., & Gerritzen, M. A. (2020). Review of climate control and space allowance during transport of pigs.*

*Broucek, J., Kisac, P., & Uhrincat, M. (2009). Effect of hot temperatures on the hematological parameters, health and performance of calves. International Journal of Biometeorology, 53(2), 201–208. https://doi.org/10.1007/s00484-008-0204-1*

*Brown-Brandl, T. M. (2013). Managing thermal stress in feedlot cattle: Environment, animal susceptibility and management options from a US perspective. Brill. https://doi.org/10.3920/978-90-8686-771-4_10*

*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. https://doi.org/10.1016/S0306-4565(02)00052-9*

*Causone, F., Corgnati, S. P., Filippi, M., & Olesen, B. W. (2010). Solar radiation and cooling load calculation for radiant systems: Definition and evaluation of the Direct Solar Load. Energy and Buildings, 42(3), 305–314. https://doi.org/10.1016/j.enbuild.2009.09.008*

*Collier, R. J., & Collier, J. L. (2012). Environmental Physiology of Livestock. https://vetbooks.ir/environmental-physiology-of-livestock/*

*Cook, N. B., Mentink, R. L., Bennett, T. B., & Burgi, K. (2007). The Effect of Heat Stress and Lameness on Time Budgets of Lactating Dairy Cows. Journal of Dairy Science, 90(4), 1674–1682. https://doi.org/10.3168/jds.2006-634*

*Da Silva, R. (2012). Weather and climate and animal production. In Guide to Agricultural Meteorological Practices (World Meteorological Organization (eds), Vol. 134, pp. 1–21). World Meteorological Organization.*

*Dovolou, E., Giannoulis, T., Nanas, I., & Amiridis, G. S. (2023). Heat Stress: A Serious Disruptor of the Reproductive Physiology of Dairy Cows. Animals, 13(11), 1846. https://doi.org/10.3390/ani13111846*

*EC Council. (2004). Council Regulation (EC) No 1/2005. On the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97.*

*EFSA. (2022a). Methodological guidance for the development of animal welfare mandates in the context of the Farm to Fork Strategy. EFSA Journal, 20(7). https://doi.org/10.2903/j.efsa.2022.7403*

*EFSA. (2022b). Welfare of cattle during transport. EFSA Journal, 20(9), e07442. https://doi.org/10.2903/j.efsa.2022.7442*

*EFSA. (2022c). Welfare of domestic birds and rabbits transported in containers. EFSA Journal, 20(9). https://doi.org/10.2903/j.efsa.2022.7441*

*EURCAW Pigs. (2020). Increased Respiratory rate. Indicator factsheet. Heat stress on farm & during transport.*

*European Commission. (2018). Consortium of the Animal Transport Guides Project (2017-rev1). Revision May 2018. 'Guide to good practices for the transport of cattle'*

*European Commission. (2019). Transport guide extreme temperatures. https://food.ec.europa.eu/document/download/22702fb3-8f8e-425e-9142-dbef9707b5df_en?filename=aw_platform_plat-conc_extreme-temp-factsh-cattle.pdf*

*Gaughan, J. B., Mader, T. L., Holt, S. M., & Lisle, A. (2008). A new heat load index for feedlot cattle1. Journal of Animal Science, 86(1), 226–234. https://doi.org/10.2527/jas.2007-0305*

*Gonzalez-Jimenez, E., & Blaxter, K. L. (1962). The metabolism and thermal regulation of calves in the first month of life. British Journal of Nutrition, 16(1), 199–212. https://doi.org/10.1079/BJN19620021*

*Grossi, S., Rossi, L., Dell'Anno, M., Biffani, S., & Rossi, C. A. S. (2021). Effects of Heated Drinking Water on the Growth Performance and Rumen Functionality of Fattening Charolaise Beef Cattle in Winter. Animals : An Open Access Journal from MDPI, 11(8), 2218. https://doi.org/10.3390/ani11082218*

*Guingal, A. (2018). Impact du stress thermique sur la production et la qualité des embryons de genisses prim'Holstein. Thèse d'exercice, Médecine vétérinaire.*

*Hales, J. R. S., & Webster, M. E. D. (1967). Respiratory function during thermal tachypnoea in sheep. The Journal of Physiology, 190(2), 241–260. https://doi.org/10.1113/jphysiol.1967.sp008205*

*Holliday, C. M., Carroll, J. A., Sanchez, N. C. B., Goerndt, M., Walker, E., & McGee, A. (2023). 62 The Impact of Hair Coat Color on Body Temperature in Beef Cattle. Journal of Animal Science, 101(Supplement_2), 2–3.* https://doi.org/10.1093/jas/skad341.002

*Islam, Md. A., Lomax, S., Doughty, A., Islam, M. R., Jay, O., Thomson, P., & Clark, C. (2021). Automated Monitoring of Cattle Heat Stress and Its Mitigation. Frontiers in Animal Science, 2, 737213.* https://doi.org/10.3389/fanim.2021.737213

*Kadzere, C. T., Murphy, M. R., Silanikove, N., & Maltz, E. (2002). Heat stress in lactating dairy cows: A review. Livestock Production Science, 77(1), 59–91.* https://doi.org/10.1016/S0301-6226(01)00330-X

*Khalifa, H. (2003). Bioclimatology and adaptation of farm animals in a changing climate. Eaap Tech, 7, 15–29.*

*Mader, T. L., Davis, M. S., & Brown-Brandl, T. (2006). Environmental factors influencing heat stress in feedlot cattle1,2. Journal of Animal Science, 84(3), 712–719.* https://doi.org/10.2527/2006.843712x

*Météo France. (2024a, March). Bilan climatique—Hiver 2023-2024.*

*Météo France. (2024b, September). Bilan climatique—Eté 2024.* https://meteofrance.fr/sites/meteofrance.fr/files/files/editorial/Bilan_ete_2024.pdf

*MSD Veterinary Manual. (n.d.). Table: Normal Rectal Temperature Ranges. MSD Veterinary Manual. Retrieved January 31, 2025, from* https://www.msdvetmanual.com/multimedia/table/normal-rectal-temperature-ranges

*National Research Council. (1971). A Guide to Environmental Research on Animals.* https://doi.org/10.17226/20608

*Olson, D. P., Papasian, C. J., & Ritter, R. C. (1980). The effects of cold stress on neonatal calves. I. Clinical condition and pathological lesions. Canadian Journal of Comparative Medicine: Revue Canadienne De Medecine Comparee, 44(1), 11–18.*

*Pasquale, V., Faucitano, L., Devillers, N., Conte, S., & Bergeron, R. (2024). Effects of space allowance on behaviour during lairage, stress physiology, skin lesion scores, and meat quality of market pigs transported in an actively ventilated vehicle in the winter. Canadian Journal of Animal Science, cjas-2024-0039.* https://doi.org/10.1139/cjas-2024-0039

*Petersen, M. K., Muscha, J. M., Mulliniks, J. T., & Roberts, A. J. (2016). Water temperature impacts water consumption by range cattle in winter 1. Journal of Animal Science, 94(10), 4297–4306.* https://doi.org/10.2527/jas.2015-0155

*Rawson, R. E., Dziuk, H. E., Good, A. L., Anderson, J. F., Bates, D. W., Ruth, G. R., & Serfass, R. C. (1989). Health and metabolic responses of young calves housed at -30 degrees C to -8 degrees C. Canadian Journal of Veterinary Research = Revue Canadienne De Recherche Veterinaire, 53(3), 268–274.*

*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. https://doi.org/10.3168/jds.2015-9901*

*Scanes, C. G. (2011). Fundamentals of animal science. Delmar Cengage Learning.*

*Schütz, K. E., Cox, N. R., & Matthews, L. R. (2008). How important is shade to dairy cattle? Choice between shade or lying following different levels of lying deprivation. Applied Animal Behaviour Science, 114(3–4), 307–318. https://doi.org/10.1016/j.applanim.2008.04.001*

*Serviento, A. M. (2022). Dynamic responses of growing pigs to heat stress modulated by prenatal life and feeding practices [Agricultural Sciences, Agrocampus Ouest]. https://theses.hal.science/tel-04061173v1*

*Silanikove, N. (2000). Effects of heat stress on the welfare of extensively managed domestic ruminants. Livestock Production Science, 67(1–2), 1–18. https://doi.org/10.1016/S0301-6226(00)00162-7*

*Sutherland, M. A., Stewart, M., & Schütz, K. E. (2013). Effects of two substrate types on the behaviour, cleanliness and thermoregulation of dairy calves. Applied Animal Behaviour Science, 147(1–2), 19–27. https://doi.org/10.1016/j.applanim.2013.04.018*

*Waubant, J. (2022). Relation entre stress thermique et production laitière: Étude préliminaire à partir de l'exemple d'un élevage laitier d'Ile-de-France. Médecine Vétérinaire et Santé Animale.*

*Young, B. A. (1981). Cold Stress as it Affects Animal Production. Journal of Animal Science, 52(1), 154–163. https://doi.org/10.2527/jas1981.521154x*

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