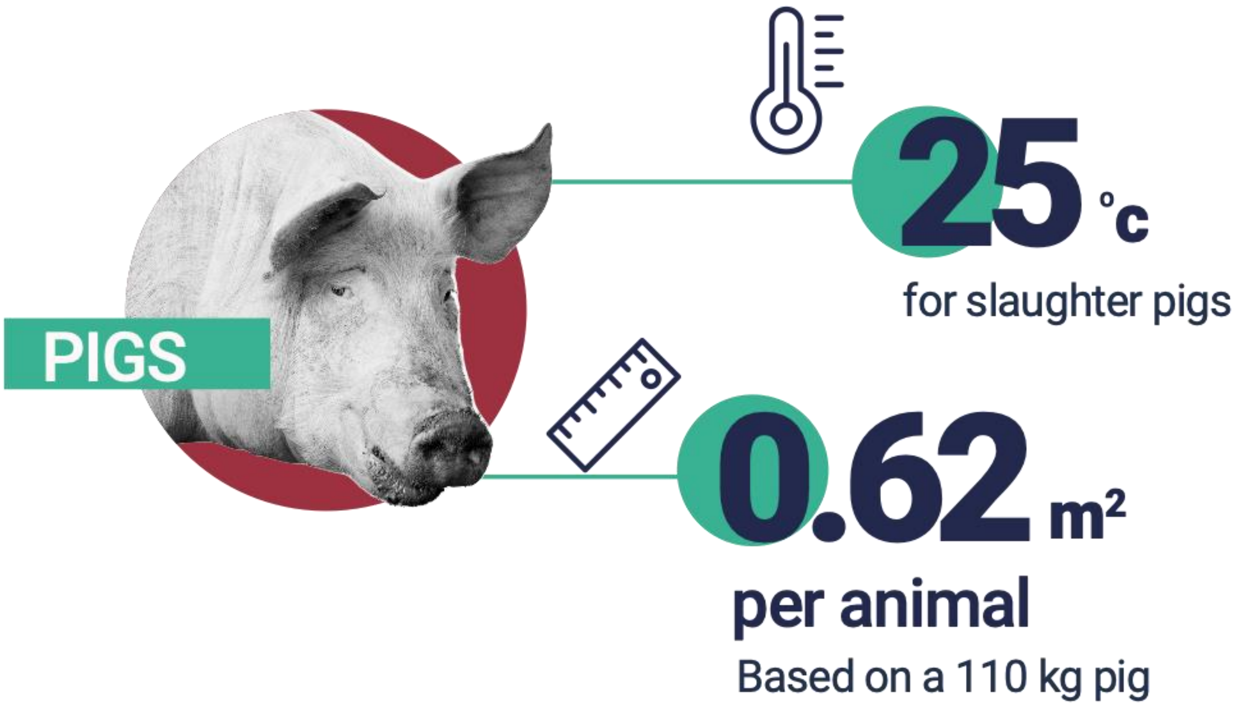
French Reference Centre for Animal Welfare



OPINION

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

Original title in French

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

Based on the EFSA Opinion (2022)

DECEMBER 2025

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

Requested by
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 Pigs during Transport (EFSA 2022b), and deals exclusively with information relating to thermal stress. The FRCAW report concentrates on three main areas. First, it details the physiological and behavioural mechanisms involved in the regulation of temperature in pigs. It then lists all those factors likely to generate thermal stress in pigs during transport. Last, the FRCAW proposes a number of mitigating actions to improve the thermal comfort of the 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 understanding of the thermal comfort conditions required by pigs (at all life stages) and 2) confirm that the suggested mitigating actions are appropriate.

Keywords

Transport / Temperature / Thermal comfort / Thermal stress / Pigs / 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 pigs 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 and amending Council Regulation (EC) No 1255/97 and repealing Council Regulation (EC) No 1/2005 (2023)
+ EFSA AHAW Panel (2022) . Welfare of pigs during transport. EFSA Journal 2022;20(9):7445, 108 pp. https://doi.org/10.2903/j.efsa.2022.7445

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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 AHAW Panel, 2022).

Conduction

Conduction transfers heat 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 an 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 transfers heat through the movement of fluids (including blood and air), transporting thermal energy from one location to another. In particular, convection increases an animal's loss of body heat through the circulation of air around it. An increase in air speed can improve the dissipation of heat by convection, which is particularly beneficial for animals 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 stress

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

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 (37-39°C for pigs, depending on their physiological stage of growth) (*Figure 3*).

Panting

Breathing in short gasps carried out with the mouth open. 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). The evaporation of water through panting is the main mechanism for heat loss in pigs at high temperatures (Huynh et al., 2005). Panting is considered to be a physical sign of heat stress.

Perceived temperature (PT)

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 limits are reached. For journeys lasting 8 hours or more, animals of all ages must also be provided with appropriate bedding.

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, AHAW Panel, 2022).

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. It can be divided 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 (TNZ)

The thermoneutral zone marks the range of ambient temperatures within which metabolic rate and heat production of a homeothermic (see thermoregulation) 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) (*Figure 3*).

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 (37-39°C for pigs, depending on their physiological stage of growth) (*Figure 3*).

Abbreviations

AT

Ambient temperature

FRCAW

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

LCT

Lower critical temperature

TCZ

Thermal comfort zone

THI

Temperature-humidity index

TNZ

Thermoneutral zone

UCT

Upper critical temperature

Figures

Figures

1 Method

This document summarises the information on thermal stress contained in the EFSA Opinion 'Welfare of Pigs during Transport' (EFSA AHAW Panel, 2022). 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 pigs. In line with the purposes of the original French expertise, including readability, not all references to the EFSA Opinion (2022) 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 Physiological and behavioural mechanisms of temperature regulation in pigs

Unlike other mammals, pigs have particular characteristics that make it harder for them to thermoregulate: they have a limited number of functioning sweat glands, their lungs are small, which limits the effectiveness of panting, and they have a thick layer of subcutaneous adipose tissue that hinders heat dissipation. As a consequence, they are particularly vulnerable to heat stress.
Like all homeothermic animals, pigs regulate their temperature mainly through behavioural and physiological adjustments.

2.1 Exposure to high temperatures

At high temperatures, pigs increase their respiratory rate and pant to increase heat dissipation through evaporation from the lungs. When sleeping, they adopt a full lateral decubitus position (lying on their sides with maximum contact with the ground), which allows them to dissipate their body heat through conduction (heat is transferred to the ground). Body heat is also dissipated into the surrounding air by convection and radiation. More frequent changes of posture can also be observed. Rectal temperature increases, and the animals decrease their food consumption and increase their water consumption. During transport, the lack of access to water, when combined with the heat and agitation of the animals, leads to hypertonic dehydration that manifests itself through an increase in plasma osmolarity. Hypertonic dehydration occurs when water loss is proportionally greater than electrolyte loss, and water moves from inside the cells of the body into the extracellular space as a compensatory mechanism. Prolonged thirst and the efforts of adjustment that pigs must make in suboptimal temperatures to maintain thermal and water homeostasis are sources of stress, including negative affective states such as discomfort and distress. In the most extreme cases, exposure to heat can lead to severe dehydration in animals who have not consumed enough water, sometimes leading to their deaths. Indeed, one study has shown that, at temperatures between 28°C and 34.2°C, the mortality rate during transport is 6.6 times higher than at temperatures below 17°C in finishing pigs (Haley et al., 2010). A different study has demonstrated that the mortality rate for 115-135 kg pigs on arrival after transport (for journeys lasting between 30 minutes and 4 hours) increases significantly once the external air temperature exceeds 25°C (up to 0.30% of pigs were dead on arrival) (Sutherland et al., 2009). In fact, the temperature inside a 4-decker lorry has been shown to rise to 32°C after 7 hours of travel, despite the fact that the outside temperature was only 23°C (Chen et al., 2024). Under such conditions, the animals can no longer regulate their core body temperatures or hydration levels and are in a state of heat and water stress.

In France, the maximum temperature recorded in 2024 was 35°C (Météo France, 2025)

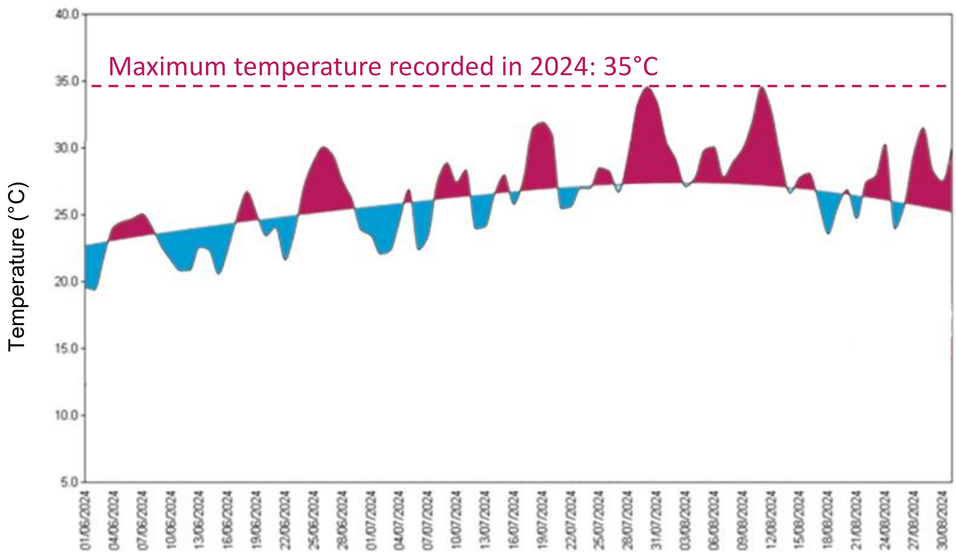

Figure 1). A record high of 46°C was reached in 2019 in the Hérault region (Météo France, 2020).

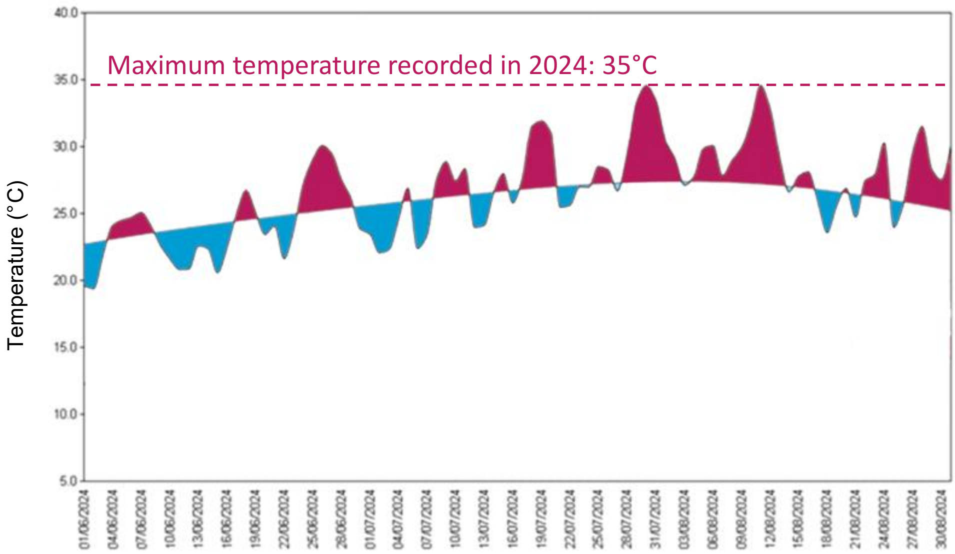

Figure 1. Profile of fluctuations in the daily maximum temperatures in France for 1 June 2024 to 31 August 2024, compared with the historical daily average from 1991-2020 (temperature profile generated from averaged 24h data from 30 weather stations in mainland France). Adapted from (Météo France, 2025)

2.2 Exposure to low temperatures

In cold temperatures, pigs generate metabolic heat by activating mechanisms such as shivering, defined as the slow and irregular vibration of any body part (Animal Transport Guides Project Consortium, 2018). Since pigs lack thick coats, they increase their activity levels and promote body contact with their conspecifics by huddling together. Increased sitting behaviour to reduce contact with the cold ground has been observed during transport in cold weather. Exposure of pigs to extreme low temperatures increases the risk of frostbite, hypothermia and hypoglycaemia, especially in piglets, who are particularly vulnerable to the cold due to their low body fat levels (Heath, 1989). When temperatures fall below 5°C during transport, the percentage of pigs unable to move on arrival increases significantly (up to 0.24% compared with around 0.12% at temperatures above 5°C) (Sutherland et al., 2009). Mortality due to transport thus increases in cold conditions (Ritter et al., 2006).

In France, the minimum temperature recorded in 2024 was -4°C (Météo France, 2025) (

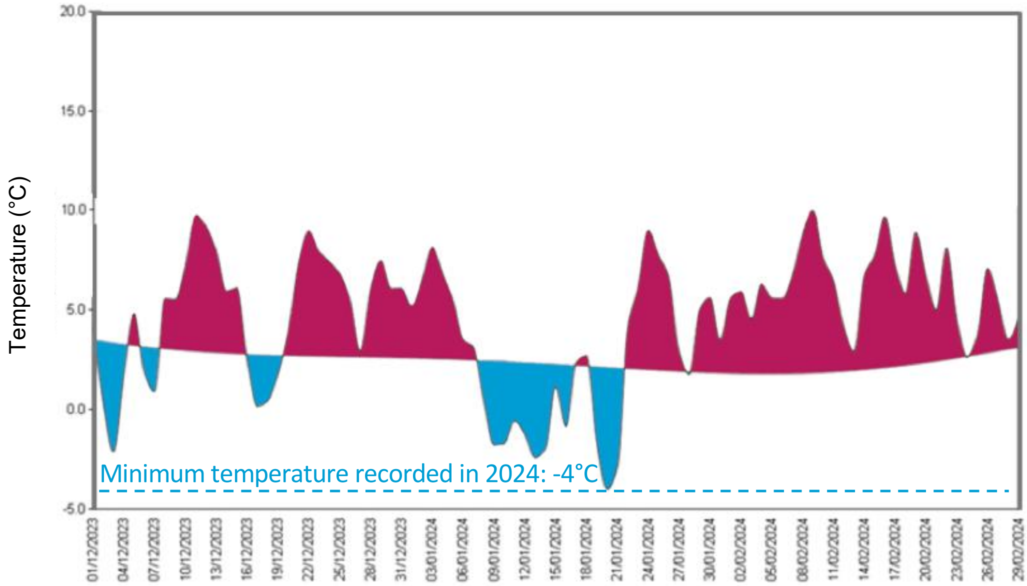

Figure 2

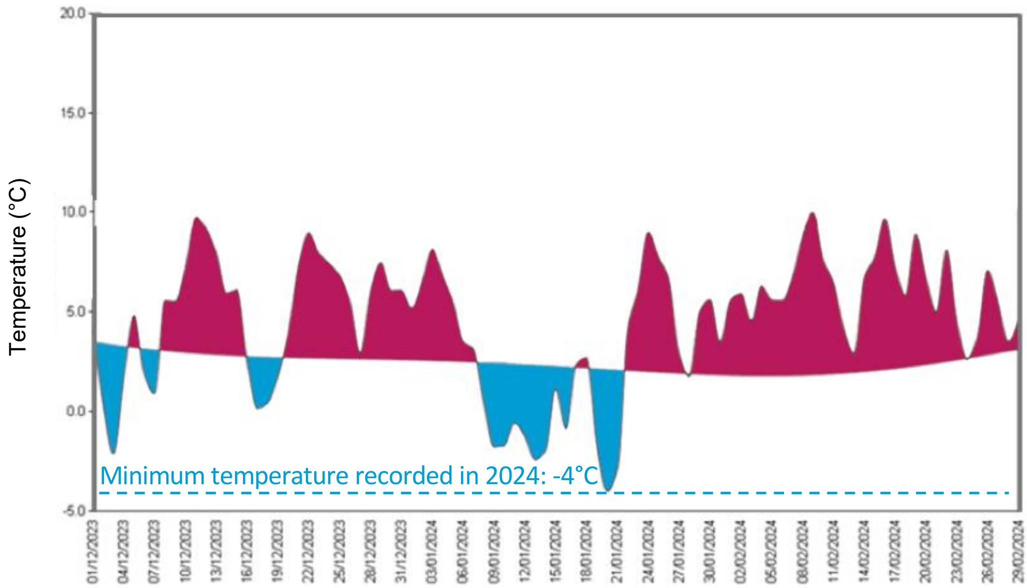

Figure 2. Profile of fluctuations in the daily minimum temperatures in France for 1 December 2023 to 29 February 2024 compared with the historical daily average from 1991-2020 (temperature profile generated from averaged 24h data from 30 weather stations in mainland France). Adapted from (Météo France, 2025)

2.3 The thermoneutral zone

The range of the Thermoneutral Zone (TNZ) varies depending on the study and criteria applied (breathing rate, food consumption, body temperature, etc.). TNZ ranges also depend on endogenous factors (particularly the category of animal) and exogenous factors (particularly humidity and air velocity) (see Paragraph 3).

Calculation of the thermoneutral zone (Figure 3): The TNZ is defined as the range of ambient temperatures within which pigs have no need to activate thermoregulatory mechanisms, since their metabolism remains relatively constant. It is bounded by the lower critical temperature (LCT) and the upper critical temperature (UTC). Below and above these critical limits, pigs begin to activate physiological mechanisms to maintain their core body temperature within the normal range, thereby increasing the risk of thermal stress. LCT and UCT vary according to a pig's category, gradually decreasing as the animal gains weight. For sows, these values are estimated at 18°C and 22-25°C respectively. For finishing pigs, LCT is around 22°C and UCT is around 25-27°C. For weaners (of around 10 kg), LCT has been estimated at 24°C and UCT at 30°C, while for boars, LCT has been calculated to be 20°C (Kemp et al., 1989).

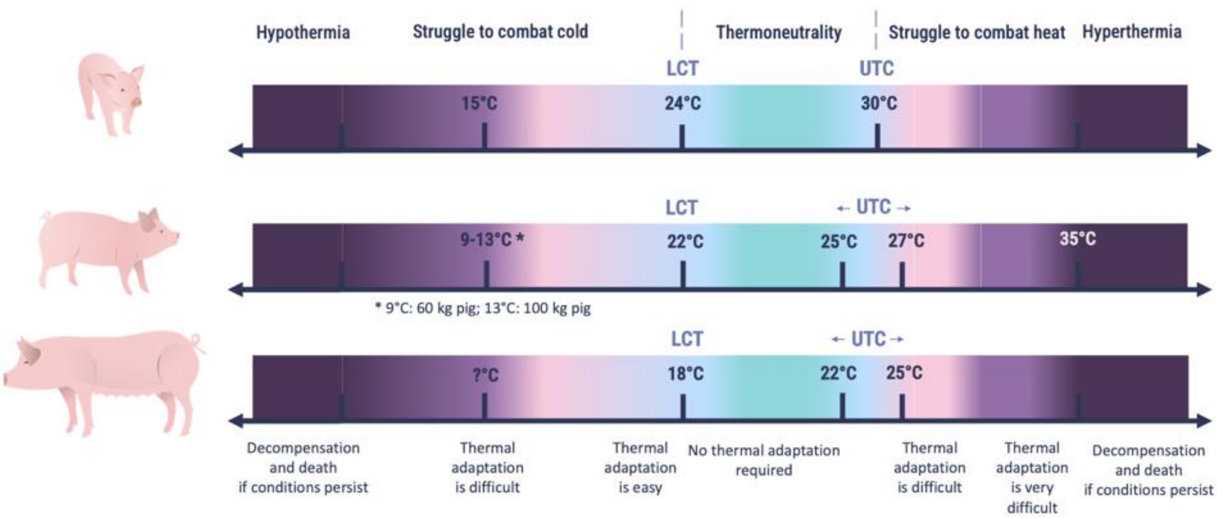

Figure 3. Diagram showing the thermoneutral zones for weaners, finishing pigs and lactating sows (from (Bruce & Clark, 1979; EFSA AHAW Panel, 2022; Gourdine et al., 2021; Serviento, 2022; Vermeer & Aarnink, 2023)). LCT: Lower critical temperature. UCT: Upper critical temperature.

To avoid any risk of thermal stress, pigs must remain within their thermoneutral zone during transport. The effective temperature, which must be measured at a point close to the animals during the journey, should never exceed the UCT, i.e. 22-25°C for sows, 25-27°C for finishing pigs, and 30°C for weaners. Equally, the effective temperature should never fall below the LCT, i.e. 18°C for sows, 22°C for finishing pigs, and 24°C for weaners.

3 Factors affecting the thermal comfort of pigs

To avoid exposing pigs to the thermal stress generated by excessive heat or cold, their environmental conditions must allow them to thermoregulate efficiently, particularly during transport, when other stress factors are in play. The factors affecting the perceived temperature (PT) for pigs (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 the thermoregulatory capacities of pigs, and therefore their TNZ, include, in particular:

+ Genetics: Genetic selection for productivity and more efficient development of lean tissue has increased the metabolic heat production of pigs reared today by around 20%, to the detriment of their ability to cope with heat stress.

+ Animal category: Lactating sows are more vulnerable to heat stress in the days leading up to weaning, when milk production is at its peak and their metabolic heat output is therefore very high. Sows at an advanced stage of gestation are also subject to high metabolic activity. Their high body heat production also makes them sensitive to heat stress. Conversely, newborn piglets and those approaching weaning are probably the least vulnerable to heat stress compared with other categories of pig, but are the most sensitive to cold stress. Indeed, young pigs have an increased risk of hypothermia and hypoglycaemia because their energy reserves are low, reducing their metabolic capacity to produce body heat. Very limited information is available on boars.

+ Body weight: Larger pigs display an increased susceptibility to heat stress due to their lower surface/body weight ratio and greater quantity of subcutaneous adipose tissue. Body heat production increases with body weight (+2% for each 5 kg increment), while the rate of heat dissipation decreases. Conversely, 20 kg piglets are more resistant than their elders when exposed to high temperatures, but are more vulnerable to low temperatures. This vulnerability is explained by (i) their relatively larger proportion of body surface area to volume, which increases the heat lost through the skin, and (ii) their low subcutaneous fat reserves, which reduce their natural thermal insulation (Bruce and Clark, 1979).

+ **Agitation level:** An animal's physical activity influences its TNZ by increasing its metabolic heat production. Thus, all loading or unloading of pigs during transport increases the risk of heat stress. For example, the extreme muscular exercise required of pigs to climb a steep access ramp or to maintain their balance in a moving vehicle leads to an increase in body temperature. The level of activity and production of metabolic heat also increase when animals not familiar with each other are mixed in a compartment (Heetkamp et al., 1995) as this causes aggressive behaviour in pigs associated with the establishment of a hierarchy.

+ **Ingestion level:** The consumption of feed induces heat production linked to digestion and the metabolic use of nutrients (Quiniou et al., 2000). Accordingly, the level of nutritional intake in pigs affects their LCT thresholds: the greater a pig's nutritional intake, the better able it is to tolerate low temperatures (Bruce & Clark, 1979). Conversely, animals whose energy intake is high in relation to their maintenance requirements (lactating sows, for example) are generally more sensitive to heat stress. The tendency in pigs to develop motion sickness is a constraint on feeding them immediately before and during transport, and it has been shown that underfed pigs produce around 1.5 times less heat than pigs fed to satiation (Del Barrio et al., 1993). It is therefore probable that fasting prior to transport increases the risk of cold stress in winter.

+ **Breed:** Leaving aside the endogenous factors listed here, such as body weight, it is not known whether particular breeds or lines of pigs from certain regions of the EU are better adapted to warm conditions than others. It is known, however, that certain breeds of pig from tropical climates are better adapted to heat stress than the commercial European Large-White breed (Gourdine et al., 2007).

3.2 Exogenous factors

Exogenous factors influence the effective temperature and therefore the TNZ of pigs during transport. Ideally, each of these factors should be considered when assessing the microclimatic transport conditions for animals. Exogenous factors include:

+ **Humidity:** At ambient temperatures above the UCT, when humidity levels are also high, the saturated air reduces the effectiveness of a pig's evaporative heat loss via the respiratory tract and further increases the risk of heat stress. For this reason, some studies add information from the temperature-humidity index (THI) to the simple measurement of ambient temperature.

+ **Solar radiation:** Depending on the material used, the sun's rays on a lorry's roof and sides can increase the temperature inside the vehicle, thereby increasing the risk of heat stress for the animals it contains. For this reason, the transport of live animals during hot spells should be scheduled at times of the day when solar radiation is at its lowest, i.e. in the morning or at night.

+ **Air circulation inside the lorry:** Air velocity increases heat loss by convection and evaporation and modifies the perceived temperature for pigs. Velocities of 0.7 m/s are perceived by pigs to be cooling, raising their LCT by 3.5°C (Randall, 1980; Chevillon et al., 1999). The movement of air can be harmful for pigs exposed to low temperatures. The intermittent exposure of weaners to air currents when the ambient temperature is only 20°C has been shown to increase their mortality rate from pathologies such as rhinitis, pneumonia and diarrhoea (Scheepens et al., 1991). In winter, cold air circulating in a vehicle travelling at 80 km/h is likely to lead to metabolic changes and considerable cold stress in piglets, and this will increase with journey length. Conversely, at high temperatures, greater air speeds help the animals to cope better with heat stress. In fact, at velocities of between 0.56 and 1.30 m/s, fattening pigs increase their feed intake by 180 g/d when the ambient temperature rises from 20 to 28°C (Massabie et al., 2001). Similarly, at 30°C, the respiratory rate of sows decreases by 7.6 bpm when the speed of nearby air flows increases from 0.19 to 0.45 m/s (Brandt et al., 2024).

There are two types of ventilation in live animal transport vehicles: passive ventilation and active forced ventilation.

Passive ventilation relies on two main air flows: (i) a horizontal flow linked to the movement of the lorry and the difference in air pressure created between the front and rear of the vehicle (which creates a continuous movement of air from the rear to the front of the lorry) and (ii) a vertical air flow produced by the chimney effect caused by temperature difference (here, warm air is drawn upwards and replaced by cold air). This uneven air flow produces areas of higher temperature in certain parts of the lorry. When the vehicle is stationary, there is no movement to create the pressure difference required for fresh air to enter and warm air to leave, limiting the effectiveness of passive ventilation. The risk of heat stress as the result of the build-up of heat and humidity therefore increases - particularly for animals located on the top deck of the vehicle (where hot air collects without being effectively replaced by cooler air).

Active forced (mechanical) ventilation in animal transport vehicles is intended to evacuate the heat and humidity generated by the animals by replacing the air inside with outdoor air. Such ventilation stabilises the thermal micro-environment and also regulates gas levels (O_2, CO_2, NH_3). Active ventilation, where fans can be activated to force the circulation of air inside the truck, is often more effective than passive ventilation in creating an air flow. In the event of prolonged stoppages in hot weather it can take over when passive ventilation is no longer sufficient. Forced ventilation systems using fans are a requirement for journeys of more than 8 hours. EC Regulation 1/2005 states that the minimum air flow rate of fans must not be less than 60 m^3/h per 100 kg live weight (Animal Transport Guides Project Consortium, 2018) and fans must be able to operate when the vehicle is stationary. However, in hot and humid weather, mechanical ventilation may not be sufficient to keep animals within their TNZ.

- **Location of the animals in the lorry:** The majority of pig transport lorries used in the European Union have between two and five decks. As a consequence of the patterns of air circulation described above, where passive ventilation is used in hot weather, animals located at the front and top of the vehicle, where air speeds are lowest, are more exposed to the risk of heat stress than those elsewhere, while the coldest locations are found on the lowest deck at the rear. With an average outside temperature of 16.6°C over a 7-hour journey, the front compartments in a lorry have been shown to reach temperatures of above 30°C for 9.3% of the journey time (Chen et al., 2024). Indeed, in summer, pig mortality during transport is highest at the front of lorries (Bench et al., 2008). During cold periods, when the outside temperature is 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). Moreover, pigs close to ventilation inlets have been shown to be exposed to strong turbulence with high air speeds (5 m/s), further accentuating their perception of cold (Chevillon et al., 1999). Thus, during the winter months, pigs transported on the upper deck, particularly those who are close to ventilation inlets, would be subjected to considerable cold stress throughout a journey.

- **Loading density:** Where animals are loaded at high densities in a lorry, this restricts heat dissipation and increases the risk of heat stress in hot weather. The EFSA cites a study where a 7°C increase in truck internal temperature was reported when the loading density was increased from 1 to 2.6 pigs/m^2 (Dewey et al., 2009) This last figure is rounded to 3 in the EFSA report. Conversely, increasing the space available through the reduction of animal numbers will reduce the total metabolic heat and humidity produced by the animals on board a vehicle. Increasing the space allowance also helps to increase evaporative cooling mechanisms via increased exposure of body surfaces to ventilation and/or conduction. Without sufficient available space, pigs cannot lie in full lateral recumbency, reducing their ability to thermoregulate effectively when temperatures are high.
  In cold weather, pigs also need sufficient space to be able to move away from cold areas, especially near ventilation inlets.

- **Mixing animals who are unfamiliar with each other:** Pigs grouped together in lorries may have come from different pens. Unfamiliarity among pigs often leads to aggressive behaviour intended to establish a hierarchy within the group. During aggressive interactions, pigs consume energy and their metabolic heat levels rise, increasing the risk of heat stress in summer. It has also been shown that the frequency of aggressive interactions between sows correlates positively with the temperature inside a transport vehicle.

- **Vertical space:** Animals may find it difficult to thermoregulate properly when vertical space is limited, as this reduces air ventilation within the vehicle (SCAHAW, 2002). In certain types of North American trailer, the temperature and relative humidity of compartments has been shown to increase during stationary periods. This occurs when the deck ceiling is less than 30 cm (for passively ventilated vehicles) or 15 cm (for actively ventilated vehicles) above the highest point of a pig's body. Increasing the vertical space by 20 cm significantly reduced the rise in temperature inside the lorry compared with the external temperature (Chen et al., 2024).

+ Waiting times: Most lorries have to spend a certain amount of time waiting, whether during loading or unloading (which lasts between 13 and 77 minutes on average), or during interruptions to the journey caused by road traffic congestion or driver breaks, which are estimated to last between 5 and 40 minutes on average (Thodberg et al., 2022). In hot weather, in stationary passively ventilated vehicles, temperatures rise rapidly to levels at which pigs suffer heat stress. By way of illustration, the internal temperature of a passively ventilated lorry rises by 1°C per minute during stationary periods, the extent of the increase being influenced by ambient temperatures, pig type, vehicle type and the space available.

+ Water deprivation: If pigs are deprived of water before and during transport, this increases the risk of heat stress, particularly in high temperatures. Even when a transport vehicle is equipped with drinkers, these cannot necessarily be accessed by all the animals, depending on where they have been placed in the lorry, nor are they always designed to suit the category of pigs being transported. Journeys lasting more than 8 hours can result in prolonged thirst, leading to the physiological changes associated with dehydration and the negative affective states associated with thirst (frustration, discomfort, distress). Nursing sows are very likely to become thirsty after a shorter period of time.

+ Journey duration: An increase in journey duration exposes pigs to the cumulative impacts of the factors mentioned here and is likely to increase the risk of thermal stress induced by, for example, a prolonged state of thirst. Behavioural and physiological signs of thirst have been observed following 8 hours of transport without proper access to water.

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

4.1 Levers for action in the event of high temperatures

Pigs must not be transported outside their TNZ, i.e. when temperatures inside the lorry exceed the UCT or fall below the LCT. The UCT and LCT vary according to the category of pig in question (**Figure 3**). If outside temperatures during the day are expected to exceed the TNZ, it is possible to mitigate the risk of heat stress to a certain extent by choosing to transport the animals at the coolest times of the day or night. There is, however, a risk involved in relying solely on this strategy (due to the uncertainties associated with weather forecasts and delays in loading and travel before the heat of the day). This underlines the need for contingency planning so that transporters can respond to unforeseen circumstances should they arise.

4.1.1 Levers for action while animals are on the lorry

Transport vehicles must be adequately designed and ventilated to keep pigs within their TNZ. When animals show signs of heat stress, the effective temperature in the truck should be lowered. This can be achieved in a number of ways:

+ **Active forced (mechanical) ventilation:** Ventilation can be increased in the hottest compartments by installing a fan on each deck at the front of the trailer, allowing air to be blown towards the rear and reducing heat stress for animals at the front in hot weather. The fans may be removed in winter (Ellis et al., 2010). Such active ventilation is particularly useful when the vehicle is stationary for long periods or if there is little vertical space between decks. Where the gap between the highest point on the animals and the ceiling is between 15 cm and 30cm, an active ventilation system should be installed; where ceilings are 30 cm or more above the animals’ highest point, passive ventilation may suffice (SCAHAW, 2002). In the event of extreme hot weather, microclimatic conditions in stationary or moving vehicles should be kept within the pigs' TNZ in each compartment and on the various decks, for example through the use of air conditioning.
+ **Passive (free) ventilation (vents or perforations):** The higher the air velocity, the lower the temperature perceived by the animal, which helps it to combat heat stress (Randall,

1980; Chevillon et al., 1999). In summer, when temperatures are high, opening the side vents (which are 40-50 cm high in France) when the vehicle is moving can create air speeds of 5 m/s for pigs located near the vents and 3 m/s for animals in the middle of the truck (Chevillon et al., 1999). The size, shape and position of the side vents for each compartment should be adjusted to achieve the ventilation rate necessary to maintain air velocity within a range that is comfortable for the pigs in all the lorry's compartments. To limit the accumulation at the front of the vehicle of heat and CO_2 from the topmost deck, the size and number of open vents should be greater in the compartments located at the front of the top deck than in the lower compartments at the rear (Ellis et al., 2010). Ideally, there should be an automatic system that would allow the opening of the side vents to be adjusted individually for each compartment and would take conditions outside the vehicle into account, these being likely to fluctuate during the journey.

+ **Monitoring:** The automatic monitoring of passive and active ventilation and of relative humidity levels and temperatures at pig height should enable the transporter to obtain the key information required to ensure the pigs' thermal comfort during transport. Sensors should be located on the different decks and in the different compartments of the lorry.

+ **Access to water:** The driver must ensure that sufficient water is stored (and/or replenished) in the vehicle's tanks and check the operation of the water supply system in each compartment of the lorry. Water drinkers must be clean, easily accessible, sufficient in number (1 drinker for every 15 pigs) and at the appropriate height for each category of pig being transported. Ideally, they should be of the same design as those used on pig farms, so that the pigs are already accustomed to them. The space available in a pen on farm is known to affect the accessibility of drinkers, the use of which is inversely correlated with animal density (Larsen & Pedersen, 2022) but there are no available data to indicate how space allowance influences water use on-board. In a transport vehicle, it would nevertheless appear that water disappearance (amount of water left in tank after journey) does not differ with space allowance or loading density (0.42; 0.5; 0.6 m^2/pig).

+ **Lorry construction materials:** When constructing vehicles, the fitting of light-coloured insulating materials that reflect solar radiation on the roof and sides of vehicles should be considered in order to limit rising temperatures inside the vehicle.

+ **Reduced loading density:** At external temperatures above 24°C, the space available in lorries should be increased by 20% to allow adult pigs or pigs at slaughter weight to adjust their posture in order to better thermoregulate (see Council Regulation (EC) No 1/2005). For pigs, movement from the sternal to the lateral position requires a 14% space increase. The recommended 20% increase in space in hot weather would thus allow pigs to lie fully recumbent on their sides in order to thermoregulate more effectively. In hot weather, pig densities should be adjusted in light of their location in the trailer, with lower densities in the front compartments.

+ **Avoiding the mixing of unfamiliar animals:** To avoid aggressive behaviours and the associated heat production, pigs from different farms or assembly centres should not be mixed in the same compartment of a vehicle.

4.1.2 Levers for action during loading and unloading, at assembly centres, control posts and during journey breaks

+ **Preparing and planning the journey:** The loading stage should be organised so that the vehicle can leave as soon as possible and, if feasible, loading should be carried out at the time of day when temperatures are at their coolest. Indeed, when pigs are transported during the hotter seasons - even for short periods - a study has shown that the greatest percentage of deaths are recorded in the afternoon, followed by the morning, with the lowest losses being observed in pigs transported at night (Machado et al., 2022). It is crucial to plan all stages of the journey up to the final destination well in advance, to avoid known sources of delay (diversions, roadworks) and to keep personnel at the final destination apprised of the arrival time, to avoid animals being kept waiting in the stationary vehicle. If necessary, the driver should ask the police for help in setting off again as soon as possible when traffic has reached a complete standstill (for example if a road is closed due to an accident (Animal Transport Guides Project Consortium, 2018)).

+ **Transit areas:** Loading and unloading bays, control posts and assembly centres must be shaded, ventilated and equipped with sufficient water supply points. The provision of water before loading and after unloading reduces the risk of heat stress. It is therefore crucial that pigs should be given access to sufficient water up to the time of loading and on arrival.

+ **Water spraying**: Misting, sprinkler or showering systems can also be used to cool the animals. Spraying pigs with water for five minutes inside the vehicle before departure and before unloading when the ambient temperature exceeds 23°C has been shown to reduce heat stress during transport and at unloading (Fox et al., 2014). The use of such systems must, however, be used in conjunction with ventilation fans, as their use without fans increases humidity and hence the vulnerability of the animals to heat. During breaks, even where animals are not unloaded from the lorry, misting can help reduce their body temperature. In a recent study, fattening pigs who received a low-intensity shower for 2 minutes every 30 minutes during the hottest part of the day consumed more feed and had lower body temperatures than un-showered pigs (Segura et al., 2024). Adopting a version of this practice during breaks, even at less frequent intervals than in the commercial feedlot-based study, would help prevent heat stress during periods of high heat.

+ **Loading ramps**: Loading ramps with a non-slip surface and at an angle of less than 15° help pigs to avoid excessive physical effort, a potential source of additional body heat.

+ **Identification of dehydrated animals:** A pig showing signs of hyperthermia or dehydration while loading should not be transported, but should be immediately removed from the loading area and left in a cool location, sprayed, and supplied with water. A **grid** detailing specific **behavioural indicators** of heat stress in pigs should be provided to each transporter, who should be trained to detect signs of weakness in animals. Grids to assess fitness for transport are already available on the website of the French Ministry of Agriculture and Food Sovereignty (Guide Pratique pour évaluer l'Aptitude au Transport des Porcs), but they are not specific to heat stress.

+ **Journey breaks on board the vehicle**: Animals must be provided with breaks during the journey to allow them to drink and rest. In a stationary vehicle, pigs must have easy access to drinkers within the lorry to prevent dehydration. Their body temperature must be reduced by spraying them with water and/or by providing active mechanical ventilation. Turning on fans in a stationary vehicle can lower the internal temperature by 2-3°C when the outside temperature is 30°C (Pasquale et al., 2024). The vehicle should be parked in a shaded area and the loading ramp should be opened.

+ **Length of breaks:** Breaks at the control post must be long enough to allow each animal to eat, drink and rest.

4.2 Levers for action in the event of low temperatures

+ **Bedding:** The addition of bedding lowers the LCT by 5-6°C for all categories of pig (Bruce & Clark, 1979). Dry litter must therefore be provided in the lorry in cold weather in sufficient quantity for the pigs to be able to avoid contact with the bare ground, burrow into it, and keep their body temperature at the comfort level they need. The bedding should be of a type to ensure that urine and faeces are absorbed, enabling the animals to remain clean and dry throughout the journey.

+ **Passive ventilation:** In winter, to avoid cold stress, the opening of vents should be kept to a minimum while permitting the air to be sufficiently refreshed. It is essential to partially cover the trailer with tarpaulin and close the side vents, as this halves air velocity at pig level (Chevillon et al., 2004).

+ **Heating:** In cold weather, lorries should be provided with internal heating.

5 Conclusions and future research

5.1 Report conclusions

When the weather forecast for all or part of a journey would prevent pigs from remaining within their thermoneutral zone (TNZ) while inside a vehicle, the decision should be made 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 pig should be transported when temperatures in the lorry are likely to be above the UCT (set at 22-25°C for sows, 25-27°C for finishing pigs and 30°C for weaners) or below the LCT (18°C for sows, 22°C for finishing pigs and 24°C for weaners). In hot weather, it is therefore preferable to arrange for journeys to be made early in the morning or during the night. With regard to low temperatures, Article 31 (Paragraph 2a) of the European Commission's draft regulation proposal specifies that "when the temperature forecast indicates temperatures below 0°C, road vehicles shall be covered and air circulation in the animal compartment controlled to protect animals from exposure to windchill during the journey" (European Commission, 2023). At an outside temperature of 0°C, the temperature inside a closed lorry does not exceed 16.9°C (Pasquale et al., 2024), which lies below the LCT for every category of pig.

The Thermal Comfort Zone (TCZ) is not as extensive as the TNZ, but it represents the ideal temperature range for the transport of pigs. In the literature, the lower limit of the TCZ is often confused with that of the TNZ. In considering the effect of transport conditions on the welfare of animals, the TCZ should be given priority over the TNZ. For this to happen, though, the limits of the TCZ for pigs need to be better defined, since they have been little studied to date.

Sensors measuring microclimatic conditions in real time at various points in the lorry should alert the transporter if the TNZ is exceeded during transport, so that the animals can be unloaded at the nearest control post. Further, for drivers to be able to carry out the appropriate preventive measures and detect signs of thermal stress in the animals being transported, it is essential that they should be properly trained in good practice and on how to interpret indicators of thermal stress in animals. If there is a risk of thermal stress, mitigation measures such as those set out in Section 4 must be taken by transporters.

5.2 Future research required

There are still many gaps in research on the transport of pigs in extreme temperatures.

Most studies on the microclimatic conditions inside vehicles used for the transport of live animals have been carried out on commercial vehicles operating outside **the European Union**. Research is needed to elucidate the profiles of changing temperatures that occur in each compartment of vehicles in Europe, taking into account the lorry types and particular climatic conditions encountered in the countries of Northern and Southern Europe.

Currently, no study has documented the **drinking systems** installed in vehicles in terms of their design (nipple or bowl drinkers), accessibility and actual use by the animals. This constitutes a knowledge gap. Minimum space considerations when transporting pigs need to take into account the space required for the installation of drinkers, as well as whether the pigs can position themselves to access them.

Research is needed to clarify the advantages and disadvantages of **fasting** pigs before transport. In cold weather, the resultant fall in energy levels makes the animals more vulnerable. Studies could, for example, usefully examine the impact of different types and quantity of feed (wet or dry) ingested before transport on the risk of nausea.

Further research is also needed into the development of passive and active **ventilation systems** that can adjust and maintain the microclimatic conditions inside a vehicle so that these remain within the TNZ of the animals being transported, regardless of whether the vehicle is stationary or moving, and for each individual compartment on each deck.

Research should also be carried out on **sensor systems** so that the transporter can monitor changes in microclimatic conditions inside the lorry throughout the journey. Although simple temperature sensors are already commonly used in pig transport, the use of improved sensors that would monitor the effects of **both temperature and humidity combined** (Temperature-Humidity Index - THI) would be a significant improvement. Measurements should be taken in each compartment and on each deck.

The use of **cameras** to monitor pig behaviours coupled with a **warning system** alerting the driver when temperatures near the pigs' bodies are approaching the UCT or LCT would enable the latter to take the necessary steps to keep the pigs within their TNZ by adjusting the ventilation in the hottest compartments. Technical issues (accuracy, maintenance, location, reliability, calibration) relating to these sensors will need to be addressed.

New infrared thermographic technologies are currently being developed. It has been shown that good correlations can be established between a simple infrared measurement of pig eye temperature and the ambient air THI, rectal temperature and respiratory rate of pigs transported in semi-arid regions (Neto et al., 2025). If vehicles were equipped with such sensors, transporters could accurately detect the risk of thermal stress in a sample of animals at any point in a journey.

Ellis et al (2010) include the following among their recommended areas for future research:

- Use of video cameras in conjunction with sensors to monitor the activity levels of the pigs and help determine the link between pig behaviour and aspects such as heat and carbon dioxide production. Such studies would make it possible to develop a **grid of** specific **behavioural indicators** of thermal stress that transporters could use.

- Use of different pig **stocking densities** on the trailer to determine the influence of the number and weight of pigs on environmental conditions.
- Use of **tracer gases** to accurately determine ventilation rates for the entire trailer and for individual compartment.
  Ventilation rates would depend on the size of the vents in the case of passive ventilation, and on the power of the fan in the case of active ventilation. Such studies would enable the driver to take targeted actions to adjust ventilation on receiving an alert that extreme temperatures had been reached in the vehicle.

5.3 Further areas for improvement

To avoid all risk of thermal stress during the transport of pigs, the alternative system of **transporting carcasses** in refrigerated lorries rather than live animals for slaughter should be encouraged. **Creating shorter distances between slaughtering sites and production sites by** constructing local abattoirs and setting up mobile slaughter units could offer an alternative to the transport of live animals, meeting the demand for short supply chains while better protecting the welfare of the animals and the quality of the meat. Although these types of abattoir can only cater for a small percentage of the total number of animals slaughtered, meeting only a niche demand, they can provide an alternative to conventional slaughter for certain types of farm and in some regions where the number of abattoirs is declining (Astruc & Terlouw, 2023).

Similarly**, establishing geographical clusters of the various types of production site** (for farrowing sows or fatteners for example) would allow a reduction in the time an animal spends being transported across its lifetime.

Additionally, **exports of** live animals outside the European Union should only be approved if the animal welfare standards involved are in line with the European regulations.

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