Review of climate control and space allowance during transport of pigs

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Contents

1. Executive Summary

This report aims to support inspectors of EU member states in understanding the science related to pig welfare concerning thermal control and space allowance during transport of pigs, especially in relation to Council Regulation EC 1/2005 on the protection of animals during transport and related operations.

The concepts of thermal comfort and thermoneutral zone are described in relation to pig transport and relevant variables are discussed such as ventilation, humidity, body weight, breed, bedding, (lack of) food and water, transport duration, air quality and space allowance.
Council Regulation EC 1/2005 specifies that during long journeys of more than 8 hours the ambient temperature inside the vehicle should be maintained between 5 °C and 30 °C, for all animals, with a +/- 5 °C tolerance (Annex I Chapter VI Article 3.1).
In order to assess thermal comfort, inspectors should in particular take into account the ambient temperature (both outside and inside the vehicle) and relative humidity (RH) as environment-based indicators of pig welfare. Indicative thermal comfort zones of pigs related to body weight are: Pigs 10-30 kg: 14-32°C if RH< 80% and 14-29°C if RH>80%; Pigs >30kg: 10-25°C (30°C with mechanical ventilation and misting devices)(SCAHAW, 2002). For adult sows and boars (pigs >160 kg) no (validated) temperature ranges are available, but these animals appear to be more prone to heat stress than smaller pigs, and thus probably need much lower maximum temperature allowances (perhaps even as low as 15-20 °C). As animal-based indicators of heat stress inspectors should look for signs of panting (high-frequent, open-mouth breathing), pumping (heavy abdominal breathing) and dog-style sitting (hind quarters down, front part up). Animal-based indicators of cold stress include shivering and huddling. In extreme cases of thermal stress animals may be exhausted/fatigued (unable to get up) or even dead on arrival (DOA).

Regarding space allowance inspectors need to be aware that pigs have different space requirements depending on the behaviour performed (standing, lying, fighting, getting access to water) and ambient temperature: under elevated ambient temperatures they will need to lie laterally (on their side) without touching other pigs in order to cool down.
Council Regulation EC 1/2005 also specifies that all pigs must at least be able to lie down and stand up in their natural position, and the loading density for pigs of around 100 kg should not exceed 235 kg/m2, while relatively more space (up to 20% more) may be required depending on the breed, size, physical condition of the pigs, the meteorological conditions and the journey time (Annex I Chapter VII D).
In order to assess space allowance, inspectors should in particular calculate or estimate the m^2/animal (depending on the size/body weights of the animals), look at available free floor space (environment-based) and dog-style sitting. Overstocking is an important risk factor for overheating, so the heat-stress indicators mentioned earlier (panting, exhaustion, DOA) may also indicate overstocking.

This report also gives examples of good practices and ends with considerations regarding the implementation of Council Regulation EC 1/2005, in particular related to thermal comfort during hot weather and space allowances for weaners and sows. EURCAW tentatively suggests these persistent concerns may be solved by making better use of available data (e.g. temperature logs, journey duration, supply breaks and loading densities of vehicles recording axle weights) and/or by considering the use of additional surveillance systems such as camera's and other sensors inside the vehicle.

2. Introduction

Recent hot summers in Europe have raised concerns about welfare in relation to transport of pigs at high environmental temperatures. This review is aimed at supporting inspectors in understanding the science related to pig welfare concerning temperature control and space allowance during transport, and offering solutions for existing problems were possible. The focus is on the scientific background relevant for inspection, and referring to more general background reviews for further reading (e.g. Transport Guides; EFSA, 2011; Rioja-Lang et al., 2019; Marahrens et al., 2011a).

This review focusses on the transport of slaughter-weight pigs, but welfare issues in other categories of pigs will also be addressed cursorily. Furthermore, in addition to actual transportation, also the periods of loading and unloading of the vehicle have been included, as well as any stops that may happen during the journey. The main issue will remain the stocking densities and temperature control during those moments.

Finally, the text deals with welfare legislative requirements and the needs of pigs. It will show on occasion that what is acceptable for legal compliance may not necessarily guarantee good pig welfare. An example is the legal requirement for pigs to be kept between 5-30 °C (plus or minus 5 °C), which may still lead to situations where they are well outside their preferred comfort zone and kept too hot or too cold.

3. Scientific knowledge on thermal control and space allowance in relation to pig welfare during transport

This section deals with the pigs' physiological and behavioural needs related to thermal control and space allowance during transport of pigs.

3.1 Importance of thermal control

Thermoneutral zone and thermal comfort

Pigs are homeothermic animals, and thus heat production and heat loss should be balanced. For this the environment surrounding the pig should fulfil certain requirements. Pigs have different strategies to influence heat production and heat loss (Aarnink et al., 2016). Under normal conditions, heat production is mainly influenced by feed intake. Heat can be lost through the following pathways: convection, conduction, radiation and evaporation (Marahrens, 2014). Heat loss through the first three mechanisms (convection, conduction and radiation) mainly depends on the temperature difference between the skin and the environment. In pigs, evaporative heat loss mainly depends on the water vapour pressure difference between inhaled and exhaled air and the respiration volume.

The pig is special among mammals because it has a very limited number of sweat glands, and therefore a limited capacity to lose heat by evaporation from the skin (Yousef, 1985). The major way pigs thermoregulate is thus via behavioural adaptation. In nature, pigs will pant, seek shade, lie down laterally on cooler surfaces without physical contact to other pigs, and wallow in mud in order to cool down (Bracke, 2011; Bracke and Spoolder, 2011). The special biology of pigs means that they are vulnerable to heat stress, if the ambient temperature is high and the environment, for example during confinement, does not allow the required thermoregulatory behaviour to keep the animal inside the thermoneutral zone (see Fig. 3.1).

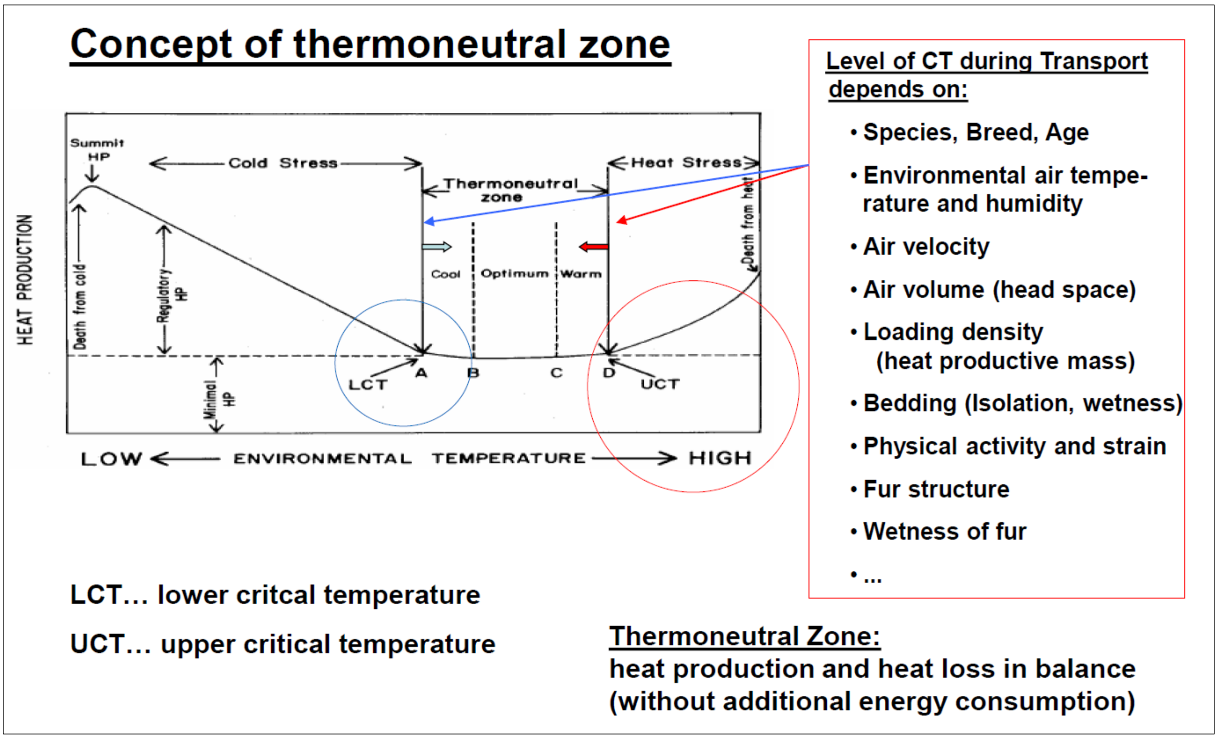

Fig. 3.1. The concept of thermal neutrality and thermal comfort (CT) (modified after Yousef, 1985).

Mount (1979) formulated a general concept of thermo-regulation of animals (Fig. 3.1). This concept is based on a certain level of feed intake under stable or resting conditions (see also Annex 1 comparing these stable conditions with transport conditions). Within the temperature zone A - D pigs can keep their (deep) body temperature constant. This thermoneutral zone can be defined as the range of environmental temperatures within which metabolic rate and heat production are (fairly) minimal, constant, and independent of the ambient temperature. Point A is called the lower critical temperature (LCT), while point D is called the upper critical temperature (UCT). The thermoneutral zone will vary depending e.g. on the size of the animal, its breed, plane of nutrition and environmental factors such as heat loss to the floor, air velocity around the animal, but also on motoric activity (e.g. maintaining balance during transport).

Ambient temperatures below A cause the body temperature to fall if little or no heat production is possible (e.g. during starvation), while above D the body temperature rises with heat production. The zone A - D can be divided into zones A - B and C – D:

- Within zone **A – B**, the body temperature is kept constant by regulation of heat production. Heat production within this zone can be increased by shivering (shivering thermogenesis), by producing extra heat without shivering (non-shivering thermogenesis by activated energy metabolism) and huddling with other animals in the group to lower heat dissipative body surfaces.
- In zone **C - D** the body temperature is kept constant by regulation of heat loss (e.g. “forced” lying behaviour to increase conductive heat dissipation, panting, etc. According to Curtis (1983) this is the zone in which pigs do not need to invest extra energy to lose heat, for example with an activation of evaporative heat loss or with shivering for heat production. In this case the lower temperature of the comfort zone (B) equals the lower temperature of the thermo-neutral zone (LCT, A). The definition of the comfort zone is subject of debate.
- In the zone **B – C** (comfort zone) neither metabolic rate nor animal behaviour is activated in any way to keep the body temperature within the normal range. Examples of undesirable behavioural changes (which are seen outside the comfort/thermoneutral zone) are extreme huddling (affects the lower temperature of the comfort zone) and lying on the slatted floor instead of the solid (insulated) floor (affects the upper temperature of the comfort zone). During heat stress, at temperatures above point D, pigs will lower their feed intake, so the situation given in Fig. 3.1, assuming a constant feed intake, is only valid for a short period after a sudden increase in ambient temperature.

In the zone from the upper threshold of the comfort zone (C) to the UCT as a limit of the thermoneutral zone (D), evaporative heat loss increases considerably. At higher environmental temperatures beyond the UCT, pigs show increased respiration rates (panting and pumping, i.e. heavy abdominal breathing) and a decreased voluntary feed intake. In addition to experiencing increased heat loss, the pigs increase the exposure of their bodies to cool air or cool and wet surfaces to increase conductive heat loss (behavioural thermoregulation). Furthermore, the effects of high environmental temperatures on pigs are expected to be more pronounced at high relative humidity levels (SCAHAW, 2002). Food restriction and food deprivation decrease the ambient temperature at which welfare is compromised due to heat stress, because the active thermoregulation required to maintain body temperature is an energy demanding procedure (both in case of heat and cold stress).

Above certain ambient temperatures, starting at approximately 22°C, clear physiological changes occur in fattening pigs (Brown-Brandl et al., 2001). For sows, and especially when lactating, the temperature threshold for physiological changes is considerably lower. The physiological indicators of heat stress include increased respiration rate and water-to-feed ratio (thirst), followed by decreased heat production and feed intake, and finally increased rectal temperature ultimately leading to death.

Decreased feed intake and increased rectal temperature are good indicators of decreased performance in heat-stressed pigs, but their welfare will already be challenged at an earlier stage.
The different strategies for heat dissipation are also based on different critical temperatures (inflection temperature points, Huynh et al., 2005). In order of appearance during rising ambient temperatures at first a higher respiration rate combined with evaporative water loss was found, followed by higher ratio of water to feed intake, total heat production and activity heat production. Behavioural changes like lying on the part of the pen with a slatted floor and lower voluntary feed intake were seen before a rise in rectal temperature as an indicator of passing the UCT limit.

Thermal requirements

An environmental temperature of 18-21°C generally has been found to support optimal productive performance of growing-finishing pigs, whereas weaned piglets and sows have other thermal requirements. In sows, the thermoneutral zone has earlier been reported to be 15-20 ^{o}C (Black et al., 1993). However, selection for increased productivity, including litter size and litter weaning weight, has reduced the modern sow's upper critical temperature (UCT according to Fig. 3.1) (Quiniou and Noblet, 1999) and increased heat production (Brown-Brandl et al., 2014, Cabezón et al., 2017). Genetic selection for productivity has thus made modern pigs more sensitive to heat stress – especially during lactation.
Whittemore (1998) gave the following comfort temperatures for pigs when kept on-farm:

- Piglets < 2 kg: 32 °C;
- Finishers: 30-60 kg: 18 °C;
- Finishers: 60-120 kg: 16 °C;
- Pregnant sows feed restricted: 18 °C (on straw: 15 °C);
- Lactating sows: 16 °C.

The author specifies the following temperatures for housing requirements: 16-20 °C for pigs 30-60 kg; 14-20 °C for finishing pigs and adult females.
A recent factsheet on transport of pigs by the European Commission (Anon., 2019) lists the following thermoneutral zones:

- Piglets <15 kg: 20-35 °C;
- Growing/finishing pigs 16-110 kg: 15-30 °C;
- Finishing pigs 111- 160 kg: 10-28 °C.

However, the scientific basis of these values, esp. for the higher temperature limits and/or for heavier (adult) pigs remains to be clarified.

High humidity will aggravate heat stress due to the reduced ability of the pigs to use evaporative cooling (e.g. by panting). Another relevant point to note is that the pigs' thermal comfort and thermoneutral zones that apply under stable conditions, i.e. in a barn or when measured in the laboratory, are likely to be different to conditions that normally apply during commercial transport. **Annex 1 of this review** discusses how these variables, such as food deprivation, vibration and motion, high stocking densities and draught, are likely to affect the pig's welfare in relation to heat stress and cold stress during transport, as compared to normal husbandry conditions.

3.2 Importance of space allowance

Relationships between space and welfare

The welfare of animals during transport is for a significant part dependent on the ability of the animals to perform normal behaviour patterns such as standing and lying, to adopt a natural body position, to minimize risks for injuries and escape from conflicts, stress and panic, and to be able to thermoregulate effectively, including being able to access sources of water.

Whether animals need to lie down and rest during transport depends on the animal's age, health and physical condition, and journey duration. Whether animals choose to lie down is dependent on the transport conditions and journey duration, if it is comfortable to do so, depending on for example stocking density (Gerritzen et al., 2012, 2013) and driving conditions (e.g. driving quality, road conditions and suspension characteristics of the transport vehicle). At some point it may be necessary for the animals to rest in order to avoid states of fatigue or exhaustion (Visser, 2014). Note that this implies that pigs may have reduced welfare on very short-distance transports (e.g. 0.5 hours) when the pigs are unable to rest and recover between the moments of elevated physical muscular activity required during loading and unloading. Pigs may also need to lie down in order to cool off. Gerritzen et al. (2012, 2013) found that when slaughter pigs are transported at a low density (180 kg/m^2) more pigs will lie down during driving than at a higher stocking density of 235 kg/m^2, which is often used under commercial conditions. As soon as the transport vehicle stopped for a break, pigs at the higher stocking density laid down as well. Based on this study, pigs seem to be motivated to lay down during transport, and will do so if they have enough space.

Space requirements

For proper welfare, all pigs on a vehicle should have sufficient space to lie down at the same time. Biologically, pigs have a strong tendency to synchronise their activities (including resting moments). However, pigs may choose to remain standing if no bedding or insufficient bedding, is provided, or if the vehicle has a poor suspension system, despite the motivation/need to lie down. The space needed for lying is reasonably well defined for pigs of about 90 to 100 kg, but less so for animals outside this range (Warriss, 1998).

In the recommendations section in Chapter 6 (Minimising welfare problems), Table 6.2 provides recommended space requirements during transport drafted earlier by Marahrens (2002). It includes a comparison of recommendations derived from (older) scientific research on biometric calculations of the amount of space pigs require in different positions and conditions. The biometric calculation uses the formula $A = k*BW^{0.67}$, where A is the floor area covered by the pigs and k is a constant value that depends on the pigs posture. Sternal lying, for example, is associated with k = 0.019 as it requires much less space to lay with the feet tucked under the body as compared to lateral lying (k=0.046), where the pig is lying 'square' on its side with the legs stretched out and without touching another pig. The pig's preference for a posture is affected by ambient temperature as pigs exposed to heat stress maximise conduction of body heat to the floor while minimises warming up due to contact with other pigs. So when it is hot, pigs need more space for resting laterally (Spoolder et al., 2012) in order to thermoregulate.

Other k values that can be found in literature are k = 0.021 for standing; 0.0274 for lying when drinkers are present; 0.046 for lateral lying without space sharing (each pig having its own 'square' for resting); 0.033 for lying with space sharing. All these values were estimated under commercial environmental conditions in a barn, with feed and water provided *ad libitum* and ambient temperatures within the animal's thermoneutral zone (Petherick, 1983; FAWC, 1991; Ekkel et al., 2003 and SCAHAW, 2002). From the table it can be derived that the minimal floor area offered on animal transport vehicles, according to European legislation, is not sufficient to grant finishing pigs of modern genetic origin enough static space in the fully recumbent body position (Arndt et al., 2019). See discussion in Chapter 6.

4. Key indicators to focus on during welfare inspections on the vehicle related to thermal control and space allowance

Based on the pigs' physiological and behavioural needs, described in Chapter 3, the welfare of animals during transport is for a significant part dependent on being able to i) thermoregulate effectively, including being able to access sources of water, and ii) on the ability of the animals to perform basic behaviours such as standing and lying, to adopt a normal position, to minimize risks for injuries, stress and panic. For both areas, animal- and resource-based indicators are suggested to facilitate welfare inspections. **They are indicated below using bold text.**

4.1 Indicators of thermal control

The thermoneutral zones during transport for different categories of pigs were outlined in Chapter 3.1. During inspections, the **temperature inside the vehicle** can be estimated. Is it outside the comfort zone, or even the thermo-neutral zone, considering the type of animal on the vehicle? And depending on the weather, are there signs of heat or cold stress? Temperature recordings/logging may be evaluated (both inside and outside the vehicle, as e.g. generally it will be hotter inside the vehicle than outside). What matters to the pigs is the inside temperature, but as the outside temperature is much more easily measured by an inspector, it may give an indication of the need to verify the inside temperature, too.

Council Regulation (EC) 1/2005 (EC, 2004, Annex I Chapter IV Article 3.3, long journeys) requires that temperature sensors must be located in the parts of the vehicle which are most likely to experience the worst environmental conditions. Using the front compartments on lower tiers and the rear compartments on upper tiers for recordings of temperatures will generally give a fairly good picture of temperature levels in the rest of the compartments on the vehicle (Christensen et al., 2007). Fig. 4.1 shows that both within and between tiers of a vehicle a considerable variation in ambient temperatures is detected by the sensors, especially during driving sessions.

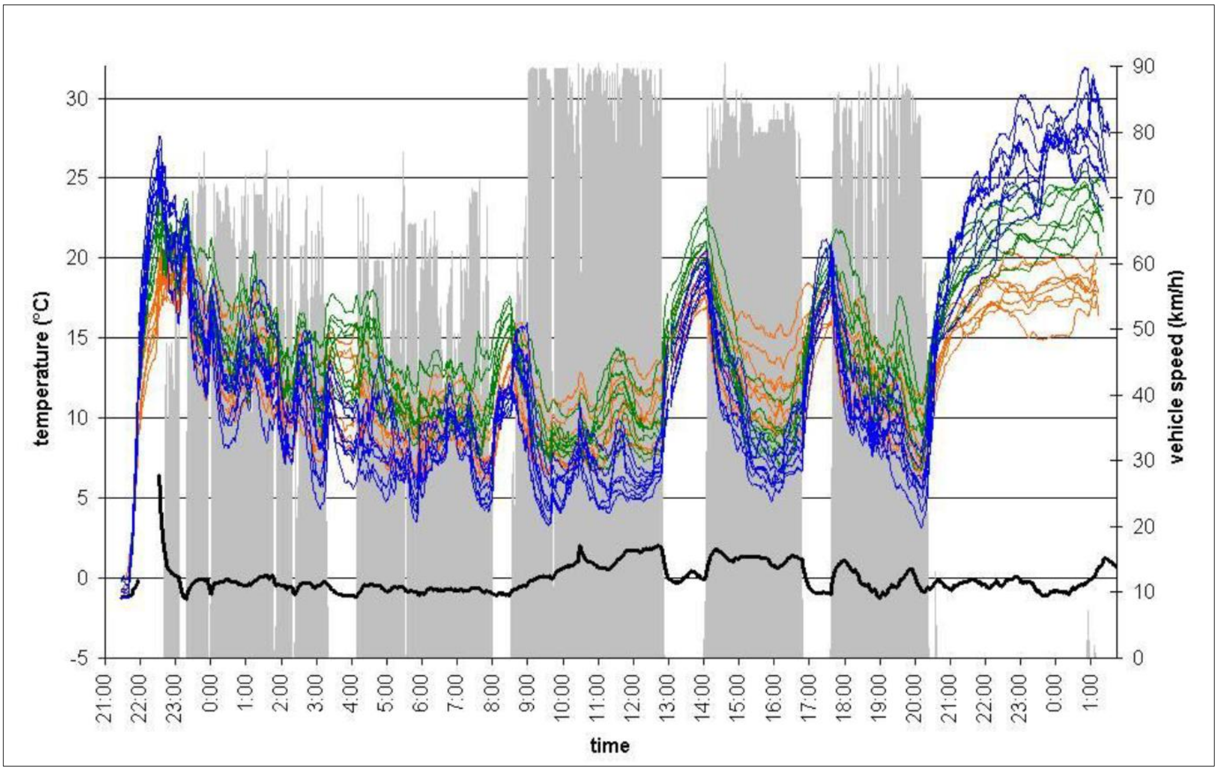

Fig. 4.1. Distribution of ambient temperatures inside a 3-tiered pig transport vehicle (blue lines: upper tier, green lines: middle tier, yellow lines: lower tier) during long transport in winter time in relation to the outside temperature (black line), vehicle speed (grey background columns), and time of day. The mechanical ventilation was switched off, thus showing the inner environment of pig transport vehicles without mechanical ventilation (as is standard for most short-distance transports). The increase of the temperatures inside the vehicle happens even with fully opened ventilation flaps (Figure adopted from Marahrens, 2014).

Heat stress

During hot weather conditions the incidence of heat stress indicators like **panting** (breathing in short gasps carried out with the mouth open), skin discoloration (patches of reddish/bluish skin) and **sitting in dog-style position** is increased (Ritter et al., 2008; Lambooij, 2014). Another indicator related to panting during heat stress is the occurrence of open-mouth breathing (Kephart et al., 2010). These behaviours are closely related (all panting is open-mouth breathing, but not all open-mouth breathing is panting). Often, during hot weather conditions pigs are lying down more frequently to increase conductive heat loss (Goumon et al., 2013). But this indicator may also be correlated to rough driving (Peeters et al. 2008). To achieve more conductive heat loss, a high stocking density and also a thick layer of bedding material are contra productive (McGlone et al., 2014). Another animal-based indicator to assess heat stress in pigs is the body surface temperature, which can be measured using infrared thermography (Xiong et al., 2015). Haley et al. (2008) and Peterson et al. (2017) found the highest number of animals **dead on arrival (DOA)** in slaughterhouses during hot weather in summer compared to other seasons, and pig mortality was related to the locations in the truck that had the highest ambient temperatures.

In the EFSA opinion on microclimate during transport (EFSA, 2004) it is stated that the air temperature inside a vehicle is only one part of the thermal environment around the animals. Extreme environmental temperatures during transport are generally considered to be one of the biggest contributors to transport losses of pigs (Haley et al., 2008, Sutherland et al., 2009). The thermoregulatory capacity of pigs in a transport environment is, especially under hot conditions, also depending on ambient **air humidity** and air velocity (Marahrens et al., 2011b, Zhao et al., 2016). High humidity will aggravate heat stress due to the reduced ability of the pigs to use evaporative cooling (e.g. by panting). Therefore, air humidity is to be taken into account when temperatures for pigs are recommended (SCAHAW, 2002).

Cold stress

Pigs transported during cold weather conditions are generally able to maintain inside vehicle temperatures in the range of the legally required 5 to 30 °C (see also Chapter 5) if the loading density and the ventilation system is adapted to this (Fig. 4.1). The main hazard for pig transports during winter time is freezing of the water supply of the animals. Water supply is required by Regulation 1/2005 (EC, 2004) for journeys over 8 hours (see also Chapter 5). Nevertheless, market-weight pigs are not accustomed to a range of colder temperatures as they have been raised in uniformly acclimatised fattening barns (Peterson et al., 2017). Cold stress is also more likely in younger pigs (weaners) as they have a lower body mass that makes it more difficult to heat up the vehicle in cold weather. Losses (**DOA**) are higher during the colder season (4 – 10 °C) compared to thermal ranges between 12 – 26 °C. Pigs transported during cold weather were standing more and had elevated heart-rate frequencies (Goumon et al., 2013). The main adaptive behaviour pigs use to maintain their body temperature during transport under cold weather conditions is "**social huddling**" to minimise body surface that dissipates sensible heat (Boon, 1981). To minimise heat dissipation sufficient amounts of appropriate bedding material should be provided and the ventilation rates inside of the vehicle must be adapted (Animal Transport Guides, 2017). The presence of wind can be beneficial during hot weather and dangerous to animal welfare during cold weather if proper precautions are not taken (Fitzgerald et al., 2009). A major hazard during transport of pigs under cold weather conditions is the occurrence of draughts. Draught is defined as the partial impact of a flow of cold air over the surface of the body that disrupts the mechanisms of thermoregulation in warm-blooded organisms (McCafferty et al., 2017). This leads to reduced body temperatures and eventually death.

Ventilation

Transport Guides (2018) clearly links ventilation to on board temperature, and differentiates between free or forced ventilation. "Free ventilation systems are common in vehicles used for short (less than 8 hours) journeys, whereas forced systems are a requirement for long-journey vehicles. According to the Regulation, the minimum air flow rate of fans should not be lower than 60 m^3/h per 100 kg live weight. The efficacy of forced ventilation systems becomes especially important with regard to transports from Northern Europe to Mediterranean regions and their hot climates. For instance, frequent stops due to traffic or border controls in hot climates can lead to heating up the vehicle interiors resulting in heat stress for livestock". Recent hot summers have made this an important issue for most of Europe.

The Guides further state that "Pigs transported over long distances may endure prolonged exposure to extreme heat or cold, or may endure radical climate changes that can increase transport stress. During the hot season, it is a legal requirement that ventilation rates should be high to maintain the temperature within the thermo-neutral zone of the animals. Air quality should not be a problem due to high airflow rates. During the cold season, ventilation rates will be lower (to maintain a thermo-neutral temperature) and air quality is likely to deteriorate" (Transport Guides, 2018). In this context, elevated ammonia concentrations may be an additional welfare problem, in particular for weaners on long-distance transports, when it is cold in winter time and the ventilation openings have been closed. Ammonia is highly irritating to the eyes and respiratory tract, and concentrations up to 50 ppm have been measured inside vehicles (Marahrens, pers. comm.).

4.2 Stocking-density indicators

Stocking density

To allow for normal species behaviour, e.g. for thermoregulation, pigs should be able to walk and reach drinkers, and be able to be lying in full lateral recumbency without touching/overlapping each other. This is especially important for pig welfare at elevated ambient temperatures, i.e. above the upper limit of their comfort zone at about 20 °C.

For inspection purposes, space allowance can be expressed as the **total weight divided by the available square meters**. However, since not all animals are weighed before transport the weight may have to be estimated, either by estimating the pigs' body weight, or, when possible, the truck's axle weight minus empty weight. An animal based measure to check for sufficient space allowance could be to estimate the possibility to lie down and express other behaviours like standing, sitting, walking and lying laterally. A final option is to estimate the free space between animals while standing in a compartment (see also Table 6.2). In Denmark a recommendation is to have 20% of free floor surface visible for 30 kg pigs, when all animals are standing. At this stocking densities pigs may nevertheless still climb on each other and risk injuries (Christensen et al., 2007).

In addition to floor space, also roof/deck heights are important and can be measured as height above the withers. There are no scientifically validated norms for optimum height. For pigs other than weaners (< 40 kg BW) the legal requirement for non-ventilated vehicles is 30 cm above the withers, and 15 cm in ventilated vehicles.

Changes in behaviour are not easy for inspectors to observe. '**Dog style sitting**' may be used as indicator, as it indicates an attempt to reduce space occupation while allowing relative ease of breathing (which is esp. relevant during hot periods). At normal temperatures sitting pigs are an indication of limited space availability (Della Villa et al., 2009). Inspectors will usually inspect vehicles after loading or shortly before unloading. At such moments, most likely pigs are standing. This may make it more difficult to assess e.g. whether there is sufficient space for resting. When pigs are lying on top of each other, this may be an indication of high/overstocking. The distribution of lying and standing animals may also give an indication.

Fatigue, injuries and death have been associated with stocking density on a vehicle (Fitzgerald et al., 2009). Data from Ritter and Ellis confirmed findings that floor space has a major effect on transport losses and suggest that these losses are minimized at a floor space of 0.462 m^2/pig or greater in pigs of approximately 130 kg body weight (BW) (Ritter et al., 2007), which is equivalent to 281 kg/m^2. Recently, Thodberg et al. (2019) reported that duration of stationary periods was one of the risk factors for deterioration in the occurrence of superficial skin lesions in sows during transport of 0-8h in Denmark.

Gerritzen et al. (2012, 2013) looked at physiological indicators and found that during and shortly after loading the body temperature of the pigs increased more in commercial, high-density groups (kept at 235 kg/m^2) compared to low-density groups (179 kg/m^2). This was related to higher activity or to stress associated with less space in the transport vehicle. They also observed an increase in heart rate during the lunch break of the driver, especially in pigs at higher loading densities. This may be related to the absence of ventilation during the lunch break, resulting in increasing ambient temperatures inside the vehicle and an elevated blood circulation to maintain body temperature in the pigs. Slaughter pigs transported at commercial loading densities were also **more fatigued** and more stressed than animals transported at lower densities.

5. Legal requirements

The legal requirements related to the transport of pigs can be found in Council Regulation EC 1/2005 on the protection of animals during transport and related operations (EC, 2004). The text below presents main requirements as paraphrases from this regulation, but not as literal citations of the legal text (for the legal text see EC, 2004). Since articles in Council Regulation EC 1/2005 do not uniquely refer to either thermal control or space allowance, they are presented below in the order in which they can be found in the Regulation.

Phrases *in italics* are particularly relevant to thermal control and/or space allowance.
Underlined phrases indicate areas of continued concern, for which we provide recommendations that may help to solve these problems in Section 6.2 (Tentative solutions to persistent welfare concerns regarding the implementation of thermal and space requirements of Council Regulation EC 1/2005).

Practical suggestions on how to implement and enforce the Regulation is offered to the members of competent authorities in several Members States. An example is the German 'Handbook on Enforcement, 2019', which is regularly updated with new scientific findings and new interpretations of open norms for Regulation (EC) No. 1/2005 (Handbook on Enforcement, 2019). Several countries have formulated their own legislation on welfare during transport, based on Regulation (EC) No. 1/2005. An example of the interpretation of the legal requirements related to space allowances (by Denmark) is given in ANNEX 2 of this review.

Article 3-6. Transport of animals is only allowed under strict rules. *The transport may not be likely to cause injury or undue suffering to the animals* and the length of the journey must be minimised. Animals must be fit for the journey, water, feed and rest must be offered in an appropriate way, *sufficient floor area and height* must be provided for the animals (appropriate to their size and the intended journey), and the safety of the animals must be ensured. Personnel handling animals must be trained and competent to fulfil their tasks without using violence.
Special requirements have been drafted for journeys of more than 8 hours (specified in Annex II, referred to via Article 5.4).

Article 3-6. Transporters are only allowed to transport animals if they hold authorisation by a competent authority and proper documentation is carried. *The transport must be* planned and *executed carefully, with weather conditions being taken into account*.

Article 14. In the case of long journeys (exceeding 8 hours) between Member States and also with third countries, the competent authority of the place of departure shall carry out appropriate checks to verify that transporters indicated in the journey log have the corresponding valid transporter authorisations, the valid certificates of approval for means of transport for long journeys and valid certificates of competence for drivers and attendants. Furthermore, part 1 of the journey log submitted by the organiser regarding the planning of the intended transport to the competent authority is realistic and indicates compliance with this Regulation.

Annex I Chapter I Section 2 ... specifies the minimum daily feed and water supply (during transport of over 24 hours) on livestock vessels or vessels transporting sea containers with pigs: concentrates: 3% of live weight of the pigs and 10 litres of fresh waters per animal.
Except if accompanied by their mother, long journeys (>8 hours) are only permitted for domestic porcine species if pigs are heavier than 10 kg.

Annex I Chapter II Article 1 Means of transport, containers and their fittings shall be designed, constructed, maintained and operated so as to:
(a) *avoid injury and suffering and to ensure the safety* of the animals;
(b) protect the animals from inclement weather, extreme temperatures and adverse changes in climatic conditions;
(c) ...
(d) ...
(e) ensure that *air quality and quantity* appropriate to the species transported can be maintained;
(f) provide access to the animals to allow them to be inspected and cared for;
(g) ...
(h) present a flooring surface that minimises the leakage of urine or faeces;
(i) provide a means of lighting sufficient for inspection and care of the animals during transport.

Note: Items c, d, and g were left out here as they do not pertain directly to space allowance or climate control during transport.

Annex I Chapter II Article 1.2. *Sufficient space* shall be provided inside the animals' compartment and at each of its levels *to ensure* that there is *adequate ventilation above the animals* when they are in a naturally standing position, *without on any account hindering their natural movement*.

Annex I Chapter III Article 1.12. Animals shall be handled and transported separately in the following cases: animals of different species, animals of significantly different sizes or ages, adult breeding boars, sexually mature males from females, animals hostile to each other, tied animals from untied animals. When the animals have been raised in compatible groups, are accustomed to each other, where separation will cause distress or where females are accompanied by dependent young these restrictions do not apply.

Annex I Chapter III Article 2.6 *Sufficient ventilation shall be provided to ensure that the needs of the animals are fully met taking into account in particular the number and type of the animals to be transported and the expected weather conditions during the journey.* Containers shall be stored in a way which does not impede their ventilation.

Annex I Chapter III. Article 2.7. During transport, animals shall be offered water, feed and the *opportunity to rest* as appropriate to their species and age, at suitable intervals. If not otherwise specified, Mammals and Birds shall be fed at least every 24 hours and watered at least every 12 hours. The water and feed shall be of good quality and presented to the animals in a way which minimises contamination. Due regard shall be paid to the need of animals to become accustomed to the mode of feeding and watering.

Annex I Chapter IV 3.2 (long journeys) 1.1. The means of transport shall be equipped with a roof of light-colour and be properly insulated.

Annex I Chapter IV 3.2 (long journeys) 1.2. Animals shall be provided with appropriate *bedding or equivalent material which guarantees their comfort appropriate to* the species, the number of animals being transported, the journey time, and *the weather*. This material has to ensure adequate absorption of urine and faeces.

Annex I Chapter IV Article 3.2 (long journeys) *The ventilation system must be capable of ensuring even distribution throughout with a minimum airflow of nominal capacity of 60 m^3/h/KN (~ 100 kg) of payload*. It must be capable of operating for at least 4 hours, independently of the vehicle engine.

Annex I Chapter IV Article 3.3 (long journeys) Means of transport by road must be fitted with a *temperature monitoring system as well as with a means of recording* such data. Sensors must be located in the parts of the lorry which, depending on its design characteristics, are most likely to experience _the worst climatic conditions_. Temperature recordings obtained in such manner shall be dated and made available to the competent authority upon request.

Annex I Chapter IV Article 3.4 (long journeys) Means of transport by road must be fitted with a _warning system in order to alert the driver_ when the temperature in the compartments where animals are located reaches the maximum or the minimum limit.

Annex I Chapter V Article 1.4. Pigs may be transported for a maximum period of 24 hours. During the journey, they must have continuous access to water.

Annex I Chapter VI Every means of transport must be fitted with an appropriate Navigation System allowing for recording and providing information equivalent to those mentioned in the journey log.

Annex I Chapter VI Article 3.1 (long journeys) Ventilation systems on means of transport by road shall be designed, constructed and maintained in such way that, at any time during the journey, whether the means of transport is stationary or moving, they are capable of _maintaining a range of temperatures from 5 °C to 30 °C within the means of transport, for all animals, with a +/- 5 °C tolerance_, depending on the outside temperature. For the planning of transports by using a weather forecast program the European Commission has clarified that a temperature tolerance of +/- 5 °C should not be applied, i.e. transports should be cancelled above 30 °C (Andriukaitis, 2018).

Annex I Chapter VII Space allowances D. Pigs, road transport _All pigs must at least be able to lie down and stand up in their natural position_. In order to comply with these minimum requirements, _the loading density for pigs of around 100 kg should not exceed 235 kg/m^2_. The breed, size and physical condition of the pigs may mean that the minimum required surface area given above has to be increased; _a maximum increase of 20% may also be required depending on the meteorological conditions and the journey time_.

6. Minimising welfare problems related to thermal control and space allowance during transport of pigs

A provisional collection of examples of good practices related to temperature control and space allowance during transport of pigs can be found in Transport Guides (2018). The sections below address some good practices regarding thermal control and space allowance that may be relevant for inspectors, and we address several concerns and their potential solutions regarding the implementation of the legislation aimed to protect pig welfare during transport.

6.1 Improving thermal control

As described above, pigs may encounter a large variation in environmental temperatures during transport. Sometimes the variation can be as large as 20 °C. This is a welfare concern. Not all areas in a vehicle provide an equal thermal environment, and conditions also vary across seasons (Xiong et al., 2018). The variation in environmental temperatures within the vehicle is dependent on the temperature outside the vehicle, and the level of control by the transporter (see Fig. 4.1). The ventilation rate should, therefore, be adapted based on the inside temperature of the vehicle that is resulting from the temperature of the incoming air (outside temperature) and the heat production by the pigs (Bruce and Clark, 1979, Fraser, 1985, Huynh et al., 2005, Grandin, 2007).

During transport the variability of thermal changes in the environment are higher (Huyn et al., 2007, Zurbrigg et al., 2017a), but opportunities to mitigate them are less compared to a stationary situation. Behavioural opportunities for sensible heat loss are hindered by high stocking density, and the possibilities for thermoregulation are further hindered by so-called 'isometric' movements for balancing of the body in a moving, vibrating vehicle (Randall, 1993).

To avoid heat stress, cooling may be provided by showers or misting when the vehicle is stationary, or when built into the vehicle. Mechanical ventilation should be started up when the temperature is above 20-21°C to keep compartment temperatures below 24°C. The misting system can be used when temperatures are above 24°C, but only for short periods of a few seconds, yet the system can be used several times during an hour (the optimum interval is not known; Christensen et al., 2007). A vehicle equipped with an automatic misting system had reduced mortality compared to a control vehicle, which the authors attributed to a better climate during loading (Christensen and Jonsson, 2007). However, also note that guidelines for the use of misting systems are not fully developed and in need of further study.

For long-distance transports, planning the journey in relation to possible overheating is important. When temperatures are likely to rise above 30 °C, pigs should not be transported, as this probably means the temperature inside the vehicle is rising above 35 °C. For pigs already in transit, the solution to overheating may not always be straightforward.

Fig. 6.1.1. Cooling of sows using a water hose after transport. Photo by Anja Putzer, Denmark.

Workers at the slaughterhouse/control post sometimes use a water hose to cool down sows that have just arrived after transport (Fig. 6.1.1). Sometimes police officers or inspectors may do the same in emergency situations (e.g. at parking lots on the highway). In this picture, sows are being showered in a holding pen after arriving, and awaiting further transport.

Fig 6.1.2. Sows in a transfer vehicle in Denmark. Photo from Carsten Kjærulff Christensen, Aarhus University.

Fig. 6.1.2 shows sows in a transfer vehicle in Denmark. The animals have space, cover from the sun and bedding. In Denmark, commercial vehicles picking up pigs on farms, can – for biosecurity reasons – not come near the buildings. However, for sows – where each farmer cannot send animals enough to fill the whole transport vehicle, the driver has to visit many farms on his way to the slaughterhouse (perhaps 5 on average, ranging from 1 to about 10). Farmers, then, load the sows onto a transfer vehicle, and use their tractor to pull the vehicle close to a public road and away from the herd. When the transport vehicle arrives, the driver loads the sows from the transfer vehicle onto the transport vehicle. In Denmark, sows can wait in such a vehicle for up to 2 hours before it counts as transport time. This picture shows such a transfer vehicle with space, cover from the sun and bedding. It is of course of crucial importance that good vehicles are being used, e.g. with a roof, water and without over-stocking (Herskin et al., 2017a).

A recent factsheet by the European Commission on pig transport during extreme temperatures by the EU animal welfare platform (Anon., 2019) covered the issue of thermal control during transport, though primarily focussing on providing recommendations for drivers, rather than inspectors. Another potentially relevant source of information is Table 4.1 in Transport Guides (2018), describing actions required to address adverse effects regarding ill health or poor welfare during transport of pigs.

6.2 Preventing overstocking

Space requirements can be calculated on the basis of pig weight using the equation $A = k*BW^{0.67}$, as explained in paragraph 3.2 above. A = area in m^2; BW is Bodyweight in kg; k = constant. The k value is the crucial element in this equation, as it varies with posture of the animals, which in turn is affected by ambient temperature. As explained, k = 0.019 reflects the space required for a standing pig or a pig that is lying on all four legs (Petherick, 1983). This does not allow walking (e.g. to a drinker), for which 0.0274 can be estimated. For full lateral lying without 'sharing' space in between legs k should be 0.046. Each pig then has its own 'square' for resting. Ekkel et al. (2003) estimated k=0.033 for lying *with* space sharing, as measured in a barn under commercial environmental conditions. Table 6.2 presents the relationship between these k values and the available space per pig.

Table 6.2. Space allocation for pigs during transport in m^2/animal depending on the pigs' body weight (BW), lying position, space requirement for drinking and resting in a commercial barn, based on the formula $A = k*BW^{0.67}$, where A is the area covered by the pigs and k is a constant value that depends mainly on posture.

Body weight (BW in kg)	Area A ($m^{2/}$pig) K=0.0192	Area A ($m^{2/}$pig) K=0.0274	Area A ($m^{2/}$pig) K=0.033	Area A ($m^{2/}$pig) K=0.046	Reg. (EC) 1/2005 ($m^{2/}$pig)*	European Council (2001)
	Sternal lying	Drinker access	Average reqrmnts	Lateral lying		Proposal GT 65 (99) 13
10	0.09	0.13		0.22	*0.04*	0.11
20	0.14	0.20	0.25	0.34	*0.09*	0.14
30	0.19	0.27	0.32	0.45	*0.13*	0.21
40	0.23	0.32	0.39	0.54	*0.17*	0.26
50	0.26	0.38	0.45	0.63	*0.21*	0.30
60	0.30	0.43	0.51	0.71	*0.26*	0.35
70	0.33	0.47	0.57	0.79	*0.30*	0.37
80	0.36	0.52	0.62	0.87	*0.34*	0.40
90	0.39	0.56	0.67	0.94	*0.38*	0.43
100	0.42	0.60	0.72	1.01	0.43	0.45
110	0.45	0.64	0.77	1.07	*0.47*	
120	0.47	0.68	0.82	1.14	*0.51*	0.55
130	0.50	0.71	0.86	1.20	*0.55*	
140	0.53	0.75	0.90	1.26	*0.60*	
150	0.55	0.79	0.95	1.32	*0.64*	0.61

160	0.58	0.82	0.99	1.38	*0.68*	
170	0.60	0.86	1.03	1.44	*0.72*	
180	0.62	0.89	1.07	1.49	*0.77*	
190	0.65	0.92	1.11	1.55	*0.81*	
200	0.67	0.95	1.15	1.60	*0.85*	0.74

*Coloured figures in italics are a linear interpolation from the value of 235 kg/m2 for 100 kg pigs (i.e. allocating 1/235 m^2 = 0.0042 m^2 per 1 kg bodyweight).

The calculations in this Table 6.2 suggest that the EU requirement of 235 kg / m^2 at 100 kg is based on sternal lying (k = 0.019), which allows that "all pigs must at least be able to lie down and stand up in their natural position" (EC, 2004) (see also Chapter 5). However, the pigs need more space when they need to be able to drink, as that requires moving to and from point-source locations in the vehicle. For this, it would be advisable to allow more space: k=0.0274. At high ambient temperatures, when the animals need to lose heat, k values between 0.033 and 0.047 are advisable. This will allow the animals to lie laterally and lose heat.

6.3 Boar transport

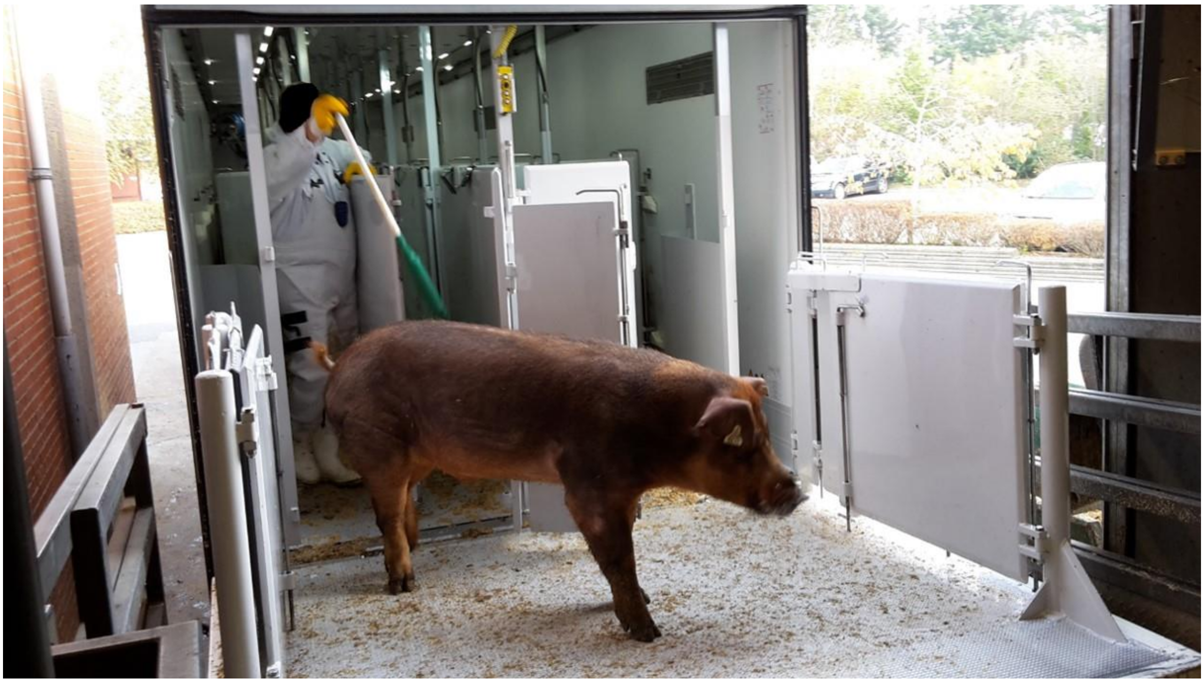

Fig. 6.2. Special vehicle to transport boars. Photo from Anja Putzer, Denmark.

Some Danish boar stations have special vehicles for boars, where they are kept individually.
On the picture (Fig. 6.2), you can see the driver unload a boar at the slaughterhouse. Loading and unloading probably takes a bit longer, but the boars win by having a much higher roof height and no risk of jumping over partitions or similar. With this solution, the vehicle only carries boars to the slaughterhouse (and no females, some of which may be in heat) and they don't have to stop at other

places or farms on the way. The vehicle is smaller than ordinary transport vehicles, and has only one tier.

6.4 Persistent welfare concerns and a possible way forward

In a fairly recent study, Voslarova et al. (2017) found that "current transport practices fail to ensure the welfare of pigs transported under other than moderate weather." The authors concluded that "Despite a decreasing trend in the mortality of finisher pigs transported for slaughter in Europe, our study suggests that current transport conditions are not efficient at ensuring the welfare of pigs during transport for longer distances and the protection of pigs against the negative impact of extreme ambient temperatures." This continues the trend observed by Baltussen et al. (2011) who found that "scientists, slaughterhouses and animal welfare groups consider that the Regulation has improved animal welfare". The number of pigs dead on arrival and the numbers of lame, dehydrated, bruised, exhausted and severely injured pigs have reduced, especially on long-distance transports. The same article also concluded that "authorities believe that the Regulation has not shown any positive impact on animal welfare" (Baltussen et al., 2011). In the present review we also identify areas of continued concern regarding the implementation of the current legislation, and we have highlighted them in Chapter 5 'Legal requirements'. The issues which are directly or indirectly linked to space and temperature are the following.

Annex I - Technical rules - Chapter I ("No animal shall be transported unless it is fit for the intended journey"). Although some guidance is given on what is constitutes a 'fit' animal, the term has no clear science-based definition and is subject to interpretation by veterinarians and inspectors.

Regarding **Annex I Chapter II point i** ("provide a means of lighting sufficient for inspection and care of the animals during transport"). Although a legal requirement, in practice it is (almost) impossible to care for animals during transport.

Concerning **Annex I Chapter III Article 1.12**, animals hostile to each other should be transported separately. However, in practice unfamiliar pigs cannot always be transported in separate compartments and will fight to establish a (new) dominance hierarchy resulting in skin lesions and worse.

Annex I Chapter IV Article 3.1 (long journeys) states that pigs must be maintained within a measured temperature range of 5-30 ^{o}C with a +/- 5 ^{o}C tolerance. The upper limit is considerably higher than the thermoneutral zone of adult pigs, and therefore far too high from a pig welfare perspective. This is evident from behavioural observations at temperatures inside the vehicle of 30 ^{o}C: pigs will show restlessness, heavy panting, dog sitting and attempts to lie laterally in order to deal with what appears to be severe heat stress.

Annex I Chapter VII specifies a maximum loading density of 235 kg/m^2 for 100 kg pigs. The legislation does not extrapolate to other weight ranges, despite the fact that this loading density is obviously wrong for the smaller weight ranges. You cannot physically keep 8 pigs of 30 kg each on one m^2, without stacking them on top of each other.

Not all of the above concerns can be alleviated in a simple way, but some can be resolved by making better use of available data. Accurate and available knowledge on e.g. temperature logs, journey duration and loading densities of vehicles via recording of axle weights can be of immediate use to inspectors. Drivers have to have this information available on long journeys, but they should be standard attributes on any transportation.

In addition to this, EURCAW recommends the use of additional surveillance systems such as cameras and other sensors inside the vehicle. Video cameras may have their limitations but are still valuable tools in monitoring stocking density as well as whether animals are panting, dog-style sitting, lying laterally, huddling or fighting. This will help the driver and inspectors to make important decisions regarding animal welfare, and could in the future be used as part of a labelling system documenting animal welfare during transport. In the relatively near future automated video-analysis may become available to, for example, allow screening for wounds (colour red) or specific behaviours such as panting using machine-learning techniques. Sensors and cameras aid the legal requirement that drivers should keep an eye on their pigs during transport (Annex I Chapter II Article 1 point i). Validated sensor technology could thus help to effectively monitor and document pig welfare during transport.

6.5 The role of training

Inspections are an important instrument to ensure the implementation and enforcement of EU animal welfare legislation. Inspectors in the different member states (MS) rely on their educational background but also on how the different Member States organize further education, to update them with the latest information. To support the Member States, the EU funds training on animal welfare legislation through the 'Better Training For Safer Food' (BTSF) initiative (https://ec.europa.eu/food/safety/btsf_en). BTSF is a Commission training initiative covering food and feed law, animal health and welfare, and plant health. A dedicated training course on 'Animal welfare during transport' is part of this.
Participation in BTSF activities is channelled through designated competent authorities (CA) in each country. BTSF contact points have been appointed in EU MS and certain other non-EU countries to coordinate participant selection. These contact points can be found on the website of the BTSF Academy (https://btsfacademy.eu/training/).

Livestock transporters play a crucial role in securing animal welfare during transport. Various studies have shown that there is a general lack of knowledge among transporters about animal welfare issues including the welfare regulations (Burnard et al., 2015; Budzik and Budzik, 2019; Herskin et al., 2017b). Nevertheless, Article 17(2) of Regulation 1/2005 states that no person shall drive, or act as an attendant on a road vehicle transporting pigs or other farm animals unless he or she holds a certificate of competence. In the European Union, the Competent Authorities of the Member States are responsible for offering and enforcing the training for drivers, followed by an exam in order to be granted the certificate of competence.

Currently, EURCAW is working on initiatives to support the Member States in offering training to inspectors on welfare issues during animal transport.

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7. References and review papers for further reading

Aarnink, A.J.A., Huynh, T.T.T., Bikker, P., 2016. Modelling heat production and heat loss in growing-finishing pigs. CIGR-AgEng conference Jun. 26–29, 2016, Aarhus, Denmark. Available at https://www.researchgate.net/profile/Andre_Aarnink/publication/306055896_Modelling_heat_production_and_heat_loss_in_growing-finishing_pigs/links/57ac824008ae0932c974897e/Modelling-heat-production-and-heat-loss-in-growing-finishing-pigs.pdf. Accessed 16-12-2019.

Aaslying, M.D., Brandt, P., Blaabjerg, L., Støier, S., 2013. Assessment and incidence of skin damage in slaughter pigs. Int. Conf. Meat Sci & Techn., Helsinki. Available at http://icomst-proceedings.helsinki.fi/papers/2013_04_13.pdf. Accessed 21-1-2020.

Andriukaitis, V., 2018. Letter of 26-4-2018. Berl 08/369.

Anon., 2019. Transport guide extreme temperatures – Pigs. Factsheet. August 2019. EU Platform Animal Welfare. Available at https://ec.europa.eu/food/sites/food/files/animals/docs/aw_platform_plat-conc_extreme-temp-factsh-pigs.pdf. Accessed 17-12-2019. See also https://ec.europa.eu/food/animals/welfare/eu-platform-animal-welfare/platform_conclusions_en.

Anon., 2019a. Research gaps on the topic of animal welfare during transport under extreme temperatures. EU Animal Welfare Platform, Sub-Group ANIMAL TRANSPORT. Available at https://ec.europa.eu/food/sites/food/files/animals/docs/aw_platform_plat-conc_extreme-temp-research-gaps.pdf. Accessed 8-1-2010.

Arndt H., Volkmann, N., Spindler, B., Hartung, J., Kemper, N., 2019. Do pigs have adequate space in animal transportation vehicles? ?—Planimetric Measurement of the Floor Area Covered by Finishing Pigs in Various Body Positions. Front. Vet. Sci. 5: 330. Available at https://www.frontiersin.org/articles/10.3389/fvets.2018.00330/full.

Baltussen, W., Gebrensbet, G., De Roest, K., 2011. Study on the impact of Regulation (EC) No 1/2005 on the protection of animals during transport. Availbable at https://ec.europa.eu/food/sites/food/files/animals/docs/aw_practice_trans_study_report_en.pdf.

Barton Gade, P., Christensen, L., 1998. Effect of different stocking densities during transport on welfare and meat quality in Danish slaughter pigs. Meat Sci. 48L: 237–247. doi:10.1016/S0309-1740(97)00098-3

Black, J.L., Mullan, B.P., Lorschy, M.L., Giles, L.R., 1993. Lactation in the sow during heat stress. Livestock Production Science 35: 153-170.

Boon, C., 1981. The effect of departures from lower critical temperature on the group postural behaviour of pigs. Animal Science 33: 71-79.

Bracke, M.B.M., 2011. Review of wallowing in pigs: Description of the behaviour and its motivational basis. Appl. Anim. Behav. Sci. 132: 1-13. http://dx.doi.org/10.1016/j.applanim.2011.01.002. Available at https://www.animalsciencepublications.org/publications/jas/articles/80/7/1819. Accessed 16-6-2016.

Bracke, M.B.M., Spoolder, H.A.M., 2011. Review of wallowing in pigs: Implications for animal welfare. Anim. Welfare 20: 347-363. Available at http://www.ufaw.org.uk/documents/BRACKE.pdf.

Brown-Brandl, T.M., Eigenberg, R.A., Nienaber, J.A., Kachmann, S.D., 2001. Thermoregulatory profile of a newer genetic line of pigs. Livest. Prod. Sci., 71: 253-260.

Brown-Brandl, T.M., Hayes, M.D., Xin, H., Nienaber, J.A., Li, H., Eigenberg, R.A., Stinn, J.P., Shepherd, T., 2014. Heat and moisture production of modern swine. ASHRAE Transactions 120: 469–89.

Bruce, J., Clark, J., 1979. Models of heat production and critical temperature for growing pigs. Anim. Sci. 28: 353-369.

Budzik, A., Budzik, T., 2019. Ethical aspects of sustainable development in Polish enterprises transporting animals for slaughter. European J. Sustainable Development 8: 347-362. doi: 10.14207/ejsd.2019.v8n3p347.

Burnard, C.L., Pitchford, W.S., Hocking Edwards, J.E., Hazel, S.J., 2015. Facilities, breed and experience affect ease of sheep handling: the livestock transporter's perspective. Animal 1-7. doi:10.1017/S1751731115000543.

Cabezón, F.A., Schinckel, A.P., Marchant-Forde, J.N., Johnson, J.S., Stwalley, R.M., 2017. Effect of floor cooling on late lactation sows under acute heat stress. Livest. Sci. 206: 113-120.

Christensen, L., Jonsson, K., 2007. Optimization of transport conditions in relation to transport mortality. Report 1 April 2007, Danish meat association, Available at http://www.dti.dk/_root/media/40667_Optimization%20of%20transport%20conditions%20in%20relation%20to%20transport%20mortality.pdf. Accessed 8-1-2020.

Christensen, L., Blaabjerg, L., Hartung, J., 2007. Investigation of pig transports for more than 8 hours in cold and warm weather conditions and of the requirements for ventilation during the transport. Report 24 July 2007, Danish meat association. Available at https://www.teknologisk.dk/_/media/64606_Investigation%20of%20pig%20transports.pdf. Accessed 9-1-2020.

Curtis, S.E., 1098. Environmental management in animal agriculture. Available at https://www.cabdirect.org/cabdirect/abstract/19842252009. Accessed 16-12-2019.

Dalla Villa, P., Marahrens, M., Velarde Calvo, A., Di Nardo, A., Kleinschmidt, N., Fuentes Alvarez, C., Truar, A., Di Fede, E., Luis Otero, J., Müller-Graf, C., 2009. Project to develop Animal Welfare Risk Assessment Guidelines on Transport. Available at https://www.efsa.europa.eu/en/supporting/pub/en-21. Accessed 9-1-2020.

Danish transport legislation, 2006. Ministerial Order 1729 (21/12/2006) on protection of animals during transport (and later specifications). Available (in Danish) at: https://www.retsinformation.dk/forms/r0710.aspx?id=2508. Accessed 28-9-2019.

EC, 2004. 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. Available at https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32005R0001 Accessed 28-9-2019.

EFSA, 2004. Opinion of the scientific panel on animal health and welfare on a request from the Commission related to standards for the microclimate inside animal road transport vehicles. The EFSA Journal (2004), 122, 1-25. Available at https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2004.122. Accessed 16-12-2019.

Haley, C., Dewey, C.E., Widowski, T., Friensdship, R., 2008. Association between in-transit losses, internal trailer temperature, and distance travelled by Ontario market hogs. Can. J. Vet. Res. 72: 385-389.

EFSA, 2011. Scientific Opinion Concerning the Welfare of Animals during Transport. EFSA Panel on Animal Health and Welfare (AHAW), European Food Safety Authority (EFSA), Parma, Italy. EFSA Journal 9: 1966. Available at https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2011.1966. Accessed 9-1-2020.

EFSA, 2004. Opinion of the Scientific Panel on Animal Health and Welfare on a request from the Commission related to Standards for the microclimate inside animal road transport vehicles. The EFSA Journal 122: 1-25.

Ekkel, E.D., Spoolder, H.A.M., Hulsegge, I., Hopster, H., 2003. Lying characteristics as determinants for space requirements in pigs. Appl. Anim. Behav. Sci. 80: 19 – 30.

FAWC, 1991. Report on the European Commission Proposals on the Transport of Animals. London, MAFF Publications.

Fitzgerald, R.F., Stalder, K.J., Matthews, J.O., Schultz Kaster, C.M., Johnson, A.K., 2009. Factors associated with fatigued, injured, and dead pig frequency during transport and lairage at a commercial abattoir. J. Anim. Sci. 87: 1156-1166.

Fraser, D., 1985. Selection of bedded and unbedded areas by pigs in relation to environmental temperature and behaviour. Appl. Anim. Behav. Sci. 14: 117-126.

Gerritzen, M.A., Marahrens, M., Steinkamp, K., Reimert, H.G.M., Van der Werf, J.T.N., Hindle, V.A., 2012. Transport conditions of fattening pigs from farm to slaughterhouse: transport of pigs for more than 8 hours at two space allowances, Wageningen UR Livestock Research. Available at https://edepot.wur.nl/240815. Accessed 9-1-2020.

Gerritzen, M.A., Hindle, V.A., Steinkamp, K., Reimert, H.G., Van der Werf, J.T., Marahrens, M., 2013. The effect of reduced loading density on pig welfare during long distance transport. Animal 7: 1849-57. doi: 10.1017/S1751731113001523.

Goumon, S., Brown, J.A., Faucitano, L., Bergeron, R., Widowski, T.M., Crowe, T., Connor, M.L., Gonyou, H.W., 2013. Effects of transport duration on maintenance behavior, heart rate and gastrointestinal tract temperature of market-weight pigs in 2 seasons. J. Anim. Sci. 91: 4925–4935.

Grandin, T., 2007. Livestock handling and transport, CABI.

Handbook on Enforcement, 2019. Handbuch Tiertransporte. Available at https://www.openagrar.de/servlets/MCRFileNodeServlet/openagrar_derivate_00022144/Handbuch-Tiertransporte-2019-05-inkl-Anlagen.pdf. Accessed 16-12-2019.

Herskin, M.S., Fogsgaard, K.K., Erichsen, D., Bonnichsen, M., Gaillard, C., Thodberg, K., 2017a. Housing of cull sows in the hours before transport to the abattoir—An initial description of sow behaviour while waiting in a transfer vehicle. Animals. doi: 10.3390/ani7010001. Available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5295151/.

Herskin, M.S., Hels, A., Anneberg, I., Thomsen, P.T., 2017b. Livestock drivers' knowledge about dairy cow fitness for transport – A Danish questionnaire survey. Research in Vet. Sci. 113: 62-66. Available at https://www.sciencedirect.com/science/article/abs/pii/S0034528817307129. Accessed 2-11-2019.

Herskin, M.S., Aaslyng, M.D., Anneberg, I., Thomsen, P.T., Gould, L.M., Thodberg, K., In press. Significant variation in the management of cull sows prior to transport for slaughter – results from a questionnaire survey among Danish pig farmers. Vet. Rec.

Huynh, T.T., Aarnink, A.J.A., Verstegen, M.W.A., Gerrits, W.J.J., Heetkamp, M.J.W., Kemp, B., Canh, T.T., 2005. Effects of increasing temperatures on physiological changes in pigs at different relative humidities. J. Anim. Sci. 83: 1385-1396.

Huynh, T.T.T., Aarnink, A.J.A., Heetkamp, M.J.W., Verstegen, M.W.A., Kemp, B., 2007. Evaporative heat loss from group-housed growing pigs at high ambient temperatures. J. Therm. Biol. 32: 293–299.

Kephart, K.B., Harper, M.T., Raines, C.R., 2010. Observations of market pigs following transport to a packing plant. J. Anim. Sci. 88: 2199–2203.

Lambooy, E., Garssen, G.J., Walstra, P., Mateman, G., Merkus, G.S.M., 1985. Transport of pigs by car for two days - Some aspects of watering and loading density. Livest. Prod. Sci. 13: 289-299.

Lambooij, E., 2014. Transport of pigs. In: Grandin, T. (Ed.) Livestock Handling and Transport. Wallingford, CABI, pp. 280–297.

Marahrens, M., 2002. Berechnungen zum Flächenbedarf von Schweinen beim Transport [Calculations of space requirements of pigs during transport]. March 11, 2002. (Pers. Comm.).

Marahrens, M., 2014. Thermal environment & animal thermoregulation during long pig road transport. Presentation. Animal Transport and Certification conference in collaboration with the 40th Annual Global Conference of ATA (Animal Transport Association), May 7, 2014, the Hague. Available at http://www.controlpost.eu/controlpost/index.php/en/journal/events/238-final-conference-of-the-animal-transport-certification-and-control-post-project. Accessed 21-1-2020.

Marahrens, M., et al., 2011a. Quality transport of farm animals - Handbook. Control post project. Available at http://www.controlpost.eu/controlpost/index.php/en/project-2/handbooks/quality-transport. Accessed 9-1-2020.

Marahrens, M., Kleinschmidt, N., Di Nardo, A., Velarde, A., Fuentes, C., Truar, A., Otero, J.L., Di Fede, E., Dalla Villa, P., 2011b. Risk assessment in animal welfare – Especially referring to animal transport. Prev. Vet. Med. 102: 157-163.

McCafferty, D.J., Pandraud, G., Gilles, J., Fabra-Puchol, M., Henry, P.Y., 2017. Animal thermoregulation: a review of insulation, physiology and behaviour relevant to temperature control in buildings. Bioinspir. Biomim. 13, https://doi.org/10.1088/1748-3190/aa9a12. Accessed 17-12-2019.

McGlone, J.J., Johnson, A.K., Sapkota, A., Kephart, R.K., 2014. Transport of market pigs: improvements in welfare and economics. In: Grandin, T. (Ed.): Livestock Handling and Transport. Wallingford: CABI, pp. 298–314.

National Pork Board, 2014. Transport Quality Assurance® Handbook, Version 5. Available at http://old.pork.org/filelibrary/tqa/2014-version5/tqahandbookv5.pdf. Accessed 9-1-2020.

NAWAC (National Animal Welfare Advisory Committee), 2011. Transport within New Zealand, Code of Welfare. Available at https://www.mpi.govt.nz/document-vault/1407. Accessed 9-11-2020.

North's Department of Agriculture DARD, 2015. 11 tips on transporting livestock in warm weather. Available at http://www.agriland.ie/farming-news/11-tips-on-transporting-livestock-in-warm-weather/. Accessed 9-1-2020.

Peeters, E., Deprez, K., Bethers, F., De Baerdemaeker, J., Auberts, A.E., Geers, R., 2008. Effect of a driver and driving style on the stress response of pigs during a short journey by trailer. Anim. Welf. 17: 189–196.

Peterson, E., Remmenga, M., Hagerman, A.D., Akkina, J.E., 2017. Use of temperature, humidity, and slaughter condemnation data to predict increases in transport losses in three classes of swine and resulting foregone revenue. Front. Vet. Sci. 4: 67.

Petherick, J.C., 1983. A biological basis for the design of space in livestock housing. In: Baxter, S.H., M.R. Baxter und J.A.C. MacCormack (Eds.): Farm animal housing and welfare. Martinus Nijhoff Publishers, Dordrecht, the Netherlands, pp. 103 – 120.

Pledl, M., Rabitsch, A., 2010. Handbuch Tiertransporte incl. Erleichterungen für landwirtschaftliche Transporte Stand 16.3.2010. Available at https://www.verbrauchergesundheit.gv.at/handel_transport/tierschutz/tt_handbuch_kurzstrecke.pdf?4vgule. Accessed 9-1-2020.

Quiniou, N., Noblet, J., 1999. Influence of high ambient temperatures on performance of multiparous lactating sows. J. Anim. Sci. 77: 2124-2134.

Randall, J.M., 1993. Environmental parameters necessary to define comfort for pigs, cattle and sheep in livestock transporters. Anim. Sci. 57: 299-307. Available at https://www.cambridge.org/core/journals/animal-science/article/environmental-parameters-necessary-to-define-comfort-for-pigs-cattle-and-sheep-in-livestock-transporters/A0BEBAFBB988AE5346D228EBF8680E58. Accessed 16-12-2019.

Rioja-Lang, F.C., Brown, J.A., Brockhoff, E.J., Faucitano, L., 2019. A review of swine transportation research on priority welfare issues: A Canadian perspective. Front. Vet. Sci. 6:36. doi: 10.3389/fvets.2019.00036. Available at https://www.frontiersin.org/articles/10.3389/fvets.2019.00036/full. Accessed 2-11-2019.

Ritter M.J., Ellis, M., Bertelsen, C.R., Bowman, R., Brinkmann, J., DeDecker, J.M., Keffaber, K.K., Murphy, C.M. Peterson, B.A., Schlipf, J.M., Wolter, B.F., 2007. Effects of distance moved during loading and floor space on the trailer during transport on losses of market weight pigs on arrival at the packing plant. J. Anim. Sci. 85: 3454-3461.

Ritter, M.J., Ellis, M., Bowman, R., Brinkmann, J., Curtis, S.E., DeDecker J.M., Mendoza, O., Murphy, C.M., Orellana, D.G., Peterson, B.A., Rojo, A., Schlipf, J.M., Wolter, B.F., 2008. Effects of season and distance moved during loading on transport losses of market-weight pigs in two commercially available types of trailer. J. Anim. Sci. 86: 3137–3145.

SCAHAW, 2002. The welfare of animals during transport (details for horses, pigs, sheep and cattle). Europäische Kommission, Scientific Committee on Animal Health and Animal Welfare. European Commission. https://ec.europa.eu/food/sites/food/files/safety/docs/sci-com_scah_out71_en.pdfS. Accessed 16-12-2019.

Soerensen, D.D., Pedersen, L.J., 2015. Infrared skin temperature measurements for monitoring health in pigs: A review. Acta Vet. Scand. 57: 5. doi: 10.1186/s13028-015-0094-2. Available at https://www.researchgate.net/publication/272084544_Infrared_skin_temperature_measurements_for_monitoring_health_in_pigs_A_review. Accessed 9-1-2020.

Spoolder, H.A.M., Aarnink, A.A.J., Vermeer, H.M., Van Riel, J. and Edwards, S.A., 2012. Effect of increasing temperature on static space requirements of group housed finishing pigs. Applied Animal Behaviour Science, 138: 229-239. doi:10.1016/j.applanim.2012.02.010.

Sutherland, M.A., McDonald, A., McGlone, J.J., 2009. Effect of variations in the environment, length of journey and type of trailer on the mortality and morbidity of pigs being transported to slaughter. Vet. Rec. 165: 13-18.

Sutherland, M.A., Backus, B.L., McGlone, J.J., 2014. Effects of Transport at Weaning on the Behavior, Physiology and Performance of Pigs. Animals 4: 657–669. doi:10.3390/ani4040657.

Thodberg, K., Fogsgaard, K.K., Herskin, M.S., 2019. Transportation of cull sows – Deterioration of clinical condition from departure and until arrival at the slaughter plant. Frontiers Vet. Sci. 6: 28.

Transport Guides (Consortium of the Animal Transport Guides Project, 2017-rev1). 2018. Guide to good practices for the transport of pigs. Revision May 2018. Available at http://animaltransportguides.eu/wp-content/uploads/2016/05/D3-Pigs-Revised-Final.pdf. Accessed 28-9-2019.

Visser, E.K., 2014. Note on minimum space allowance and compartment height for cattle and pigs during transport. Wageningen UR Livestock Research. Available at https://edepot.wur.nl/330021. Accessed 9-1-2020.

Von Holleben, K., 2015. bsi Schwarzenbek - angewandter Tierschutz bei Transport und Schlachtung - unabhängigetierärztliche Kompetenz. Personal communication. Available at http://www.bsi-schwarzenbek.de. Accessed 9-1-2020.

Voslarova, E., Vecerek, V., Passantino, A., Chloupek, P., Bedanova, I., 2017. Transport losses in finisher pigs: impact of transport distance and season of the year. Asian-Australas J. Anim. Sci. 30: 119-124. DOI: https://doi.org/10.5713/ajas.16.0265

Warriss, P., 1998. Choosing appropriate space allowances for slaughter pigs transported by road: a review. Vet. Record 142: 449-454.

Whittemore, C., 1998. The Science and Practice of Pig Production. 2nd Ed. Blackwell science, Oxford.

Xiong, Y., Green, A., Gates, R.S., 2015. Characteristics of trailer thermal environment during commercial swine transport managed under U.S. industry guidelines. Animals 5: 226–244.

Xiong, Y., Gates, R.S., Green-Miller, A.R., 2018. Factors Affecting Trailer Thermal Environment Experienced by Market Pigs Transported in the US. *Animals 8:* 203.

Yousef, M.K., 1985. Thermoneutral zone. In: Stress Physiology in Livestock, M.K. Yousef (ed.), Vol.I., CRC Press, Boca Raton, FL, pp. 47-54.

Zhao, Y., Yin, H., Harmon, J.D., Bass, T.J., 2016. Mortality rate of weaned and feeder pigs as affected by groiund transportation conditions. Trans. Amerc. Soc. Agric. Biol. Eng. 59: 943-948.

Zurbrigg, K., Van Dreumel, T., Rothschild, M.F., Alves, D., Friendship, R., O'Sullivan, T., 2017a. Pig-level risk factors for in-transit losses in swine: a review. Can. J. Anim. Sci. 97: 339–346.

ANNEXES

ANNEX 1 Risks of welfare-assessment bias when applying findings on thermal comfort under static housing conditions to thermal comfort under transport conditions

Care should be taken when extrapolating findings obtained from experiments in conventional barns to transport conditions.

1. Transported pigs are food deprived. This implies their energy metabolism first switches to catabolic breakdown of energy reserves (e.g. from the muscles), slowing down and later being restricted to central vital functions (heart beat; respiration). Therefore, there may be little/no energy available for (additional requirements related to) thermal regulation. This seems to suggest that
    a. the thermoneutral-zone (TNZ) and comfort-zone (CZ) bands are both elevated (moved up), perhaps without remaining equally wide as some behavioural adaptation/requirements for thermoregulation (e.g. increased respiration, huddling) remain possible, while others (e.g. lying on slatted floor; avoiding body contact) are not (see point 4 below), and
    b. cold stress and heat stress will be aggravated (more rapidly/steeply develop as the temperature decreases and increases respectively) as soon as enhanced muscle activity is required (e.g. for shivering/panting), since/for as long as the pigs are food deprived (i.e. their energy tank is empty). Glycogen reserves are probably readily depleted during loading (as the pigs are normally not used to any significant physical exercise), requiring the pigs to burn fat during transport for thermoregulation.
2. Transported pigs are exposed to vibration and motion forces. This requires isometric muscle activity (for maintaining balance) which implies producing heat.
    a. This may make the TNZ & CZ bands narrower (the UCT will move down due to the extra muscle-heat production and the LCT may be raised or not be affected (as the muscle activity due to transport may be considered equivalent to/exchangeable for shivering activity; if it is additional muscular activity, the LCT may even be lowered)
    b. This may aggravate the impact of food deprivation (see point 1, esp. 1b)
3. Pigs are generally transported at high (max. allowed) stocking densities. This makes it impossible for the pigs to avoid contact with other pigs (radiative heat dissipation) and/or lay flat on the floor to lose heat (conductive heat dissipation), and it may lead to increased relative humidity (RH; and reduced air quality) at the animal level (if the ventilation is not optimal). High stocking densities also make it difficult/impossible to drink water (if it is provided in the vehicle in the first place). This will
    a. move the TNZ and CZ band down and
    b. aggravate heat stress (but not (so much) aggravate cold stress as in case of cold stress, pigs can huddle more/fairly easily at high stocking densities.)
4. Transported pigs are at risk of draughts (i.e. local airflow that is either too cold or too hot compared to what is comfortable for the pig). The air flow hits the body surface only partially,

which is why thermoregulation does not respond. Partial cooling occurs, which cannot be counter-regulated. Thus,

a. Some pigs may be more affected than others within the same vehicle, even in the same tier/pen, and it may probably even happen that some pigs are too cold and others too hot at the same time or during the same journey.

The overall impact on welfare, esp. of points 1b, 3b and 4, also depends to a considerable extent on e.g. the transport duration (more problematic the longer the transport) and on the type of pig (e.g. larger animals are more prone to heat stress and some animals, like cull sows, may not be very fit and/or they may be thin or fat, which may alter their ability to thermoregulate). Further empirical research is needed to determine TNZ & CZ of pigs of various body weights under transport conditions, preferably for different categories of pigs.

ANNEX 2 An example of the legal interpretation of space requirements in EU Regulation 1/2005 from Denmark

Though its scientific basis is not fully clear (probably related to EFSA, 2004, p. 47), the Danish transport legislation (2006) states in §9 that during transport of pigs of as 40 kg body weight, the height between decks should be at least as shown in Table II.1.

Table II.1. Required height between decks (measured from the highest point of the floor to the lowest point of the ceiling on the above deck) for transport of pigs in relation to body size (Danish transport legislation, 2006).

Mean body weight	When mechanical ventilation is in use, cm	When other ventilation is in use, cm
40	74	89
50	77	92
70	84	99
90	90	105
100	92	107
110	95	110
130	99	114
150	103	118
170	106	121
190	109	124
210	111	126
230	112	127

Notably, while the legislation concerns pigs of 40 kg and more, Denmark is transporting many weaned pigs below 40 kg each year. However, if the weight of the transported animals does not correspond with the values provided in the table, the required height can be calculated as minimum values by interpolation (cf. EFSA, 2004).

It is further specified in the Danish legislation that the mechanical ventilation must ensure sufficient and evenly distributed ventilation with a nominal ventilation capacity of at least 61 m^3/h per 100 kg of pigs.

There should always, in the room where the pigs are kept, and at all levels in the room, be space allowing good ventilation over the pigs, when they stand in an unhindered position, and their natural movements must by no means be prevented.

In Appendix 2 of the Danish transport legislation (2006), it is specified that for pigs, the following space allowances are required for transports below and above 8h as shown in Table II.2.

Table II.2. Space allowances for pigs of different body weights transported for less than 8 hours (< 8h) or more than 8 hours (> 8h) (Danish transport legislation, 2006).

Live weight (kg)	**Area (m^2) per**	**Area (m^2) per**

	animal < 8h	animal > 8h
25	0.17	0.20
50	0.26	0.31
75	0.33	0.39
100	0.42	0.50
200	0.70	0.84
250 or more	0.80	0.96

In addition to the legal requirements mentioned above, the competent authorities in Denmark have guidelines for the control of vehicles. The tables below are intended as support for the competent authorities, but the assessment still mainly relies on the visual inspection on site, checking whether the conditions on the vehicles allow the animals to lie down and stand up in a natural position, as specified in Council Regulation (EC) 1/2005 (EC, 2004).

When the stocking density (kg animal/m^2) is calculated, the average body weight of the animals is used based on the weight of the whole load. If the vehicle contains animals of rather varying size (which therefore should be kept separated), the average body weight and stocking density should be assessed per room (Table II.3).

Table II.3. Maximum space allowances for transport of pigs of different body weights according to the Danish Transport Legislation (2006).

Body weight, kg	Pigs/m², <8h	m²/pig, <8h	Pigs/m², >8h	m²/pig, >8h
10	10.526	0.095	8.399	0.119
20	6.897	0.145	5.568	0.180
30	5.319	0.188	4.505	0.222
40	4.464	0.224	3.759	0.266
50	3.846	0.260	3.226	0.310
60	3.472	0.288	2.924	0.342
70	3.165	0.316	2.674	0.374
80	2.874	0.348	2.427	0.412
90	2.604	0.384	2.193	0.456
100	2.381	0.420	2.000	0.500
110	2.232	0.448	1.873	0.534
120	2.101	0.476	1.761	0.568
130	1.984	0.504	1.661	0.602
140	1.880	0.532	1.572	0.636
150	1.786	0.560	1.493	0.670
160	1.701	0.588	1.420	0.704
170	1.623	0.616	1.355	0.738
180	1.553	0.644	1.295	0.772
190	1.488	0.672	1.241	0.806
200	1.429	0.700	1.190	0.840
210	1.389	0.720	1.157	0.864
220	1.351	0.740	1.126	0.888
230	1.316	0.760	1.096	0.912
240	1.282	0.780	1.068	0.936
250	1.250	0.800	1.042	0.960