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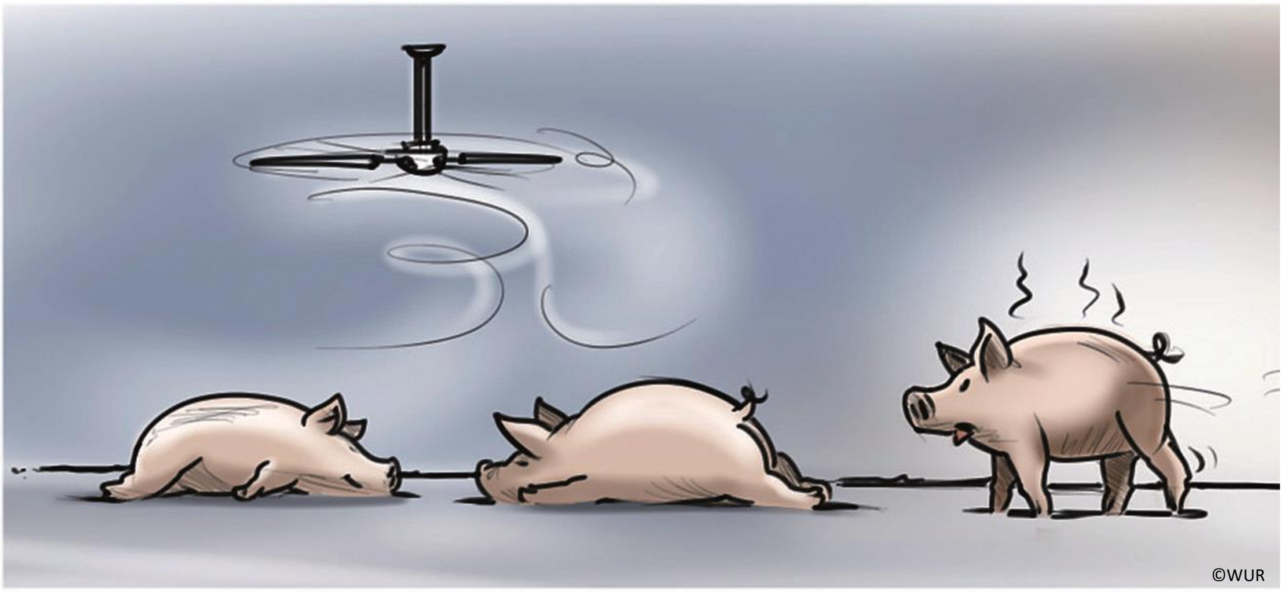
for Animal Welfare *Pigs*

Review on heat stress in pigs on farm

Herman M. Vermeer, André J.A. Aarnink



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This review aims to support welfare inspectors in the field of climate control on pig farms, in particular at high temperatures. Heat stress in all pig categories will be described, but with the focus on lactating sows and finishing pigs. The review is concluded with practical advices to prevent heat stress in pigs, beneficial for animal welfare, performance and working conditions.

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1 Executive Summary

With increasing global temperatures, the risk of heat stress for farm animals is also growing. As pigs are not able to sweat and in livestock houses they generally do not have the opportunity to wet themselves, an ambient temperature above the upper critical temperature (UCT) leads to reduced welfare and performance. This UCT varies per pig category (including weight) and is considerably lower for lactating sows than for newborn piglets. At high humidity even lower temperatures can lead to heat stress, i.e. above a calculated temperature-humidity-index (THI) above 84 for finishers. In case of upcoming heat stress the pig reacts in different physiological and behavioural ways to maintain homeothermia. The pig becomes less active, reduces feed intake, adapts its lying behaviour and increases breathing frequency. If these measures are not sufficient the core body temperature will rise and ultimately lead to death. The scientific knowledge in this review aims to support welfare inspectors in the field of climate control on pig farms, in particular at high temperatures.

Useful indicators for heat stress can be environment based or animal based. Environment based indicators are the above mentioned room temperature and relative humidity, combined as THI. But also the absence of air cooling or pig cooling facilities increase the risk of heat stress. Animal based indicators are animal and pen fouling, skin and body temperature, respiration (breathing frequency, panting, open mouth), lying pattern, feed intake and water intake. Room temperature, relative humidity, panting and pig fouling are recommended in this review as the most useful and proven indicators for heat stress.

Measures to prevent heat stress can preferably be combined with the weather forecast to prevent heat accumulation in pig buildings. The main measure is to regularly check indoor temperature and relative humidity and to use a table on corresponding THI values to assess the heat burden of animals and to start with countermeasures before the threshold is reached. The feed ration can be lowered to prevent mortality and left overs in the trough. To prevent arousal in the house, the feeding time could be postponed to cooler period, taking into account the legal requirements for feeding. If possible, veterinary treatments should be postponed. Drinkers should be checked (flow rate, fresh, clean, cool) and ventilation rate maximized. Incoming air can be cooled by water evaporation: water spraying (fog/mist) in the air inlet. Air speed can be increased by inside circulation of air and at very high temperatures this could be combined by wetting the pigs. Direct sunshine through the windows can be prevented by insulation or use of white chalk. Chalk or moisten the roof can also keep the roof somewhat cooler. As pigs like to maximize heat loss by lying laterally without contact with penmates the caretaker shall try to maximize the space allocation per pig.

2 Introduction

European summers became hotter in recent years, with negative effects on welfare, health and physiology of production animals (Ross et al., 2015). Compared to the outdoor temperature the indoor temperature will be even more effected (Mikovits et al., 2019). The scientific knowledge in this review aims to support welfare inspectors in the field of climate control on pig farms, in particular at high temperatures. Possible solutions to heat stress can help to prevent welfare problems. In this review we focus on the most relevant scientific information and if available we refer to more background sources from e.g. EFSA, EURCAW-Pigs, scientific journals, applied research and practical examples. Heat stress in all pig categories will be described, but with the focus on lactating sows and finishing pigs. These categories have the highest heat production due to high daily feed intake per kg bodyweight and a high body weight to skin surface ratio.

This review is about problems in pig houses, on farm and not during transportation and at abattoirs. Although temperature differences between countries during summer are large, the information and recommendations are valid for all European pig farms. There are not many legal requirements included in the respective EU Welfare Directives on indoor climate in pig houses, although some countries have more detailed rules. This implicates that inspectors need both animal based and environment based indicators to assess whether pigs may suffer from heat stress and to enforce these open formulated legislative requirements. With such indicators it should be possible to assess whether pigs are kept within their thermoneutral zone and improve their welfare. Theoretically heat stress starts when the ambient temperature exceeds the upper critical temperature (UCT) of the thermoneutral zone. Above UCT pigs will actively increase heat loss to maintain their core body temperature. It should be noted that also between the upper limit of the comfort zone and UCT pigs already make adaptations to increase heat loss, but these changes do not affect heat production. Active changes in pigs to increase heat loss are physiological (e.g. increase in respiration rate) and/or behavioural adaptations (e.g. lying on slatted floor instead of on an insulated solid floor). The UCT depends on age (body weight) and stage of production. When the UCT is not exceeded it is both beneficial for animal welfare as for profitability. Figure 3.1.1 shows a schematic presentation of the thermal requirements of pigs with the red box indicating occurrence of heat stress (EFSA, 2004).
We conclude this review with practical advices to prevent heat stress in pigs, beneficial for animal welfare, performance and working conditions.

3 Scientific knowledge on the behaviour and physiology of pigs in relation to heat stress

This chapter provides scientific knowledge on behavioural and physiological needs of pigs regarding thermal environment. By addressing these specific needs within this chapter, certain “heat stress indicators” will be identified. These indicators point at potential welfare risks. The scientific knowledge presented in this chapter can help inspectors to understand the relevance of the indicators for the welfare of pigs and why it is important to focus on these indicators during inspections.

3.1 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., 2006). Under normal conditions, heat production is mainly influenced by feed intake. Heat can be lost through the following pathways: convection (air flow), conduction (contact), radiation (electromagnetic waves) and evaporation (water to water vapor) (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.

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). In pigs, evaporative heat loss mainly depends on the water vapour pressure difference between inhaled and exhaled air and the respiration volume. Thus, the major way pigs thermoregulate is via behavioural adaptation. In nature, pigs will increase respiration rate (and 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). The wallowing is not only because the mud is cooler, but also to wet themselves to enhance evaporation. The specific 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. 3.1.1).

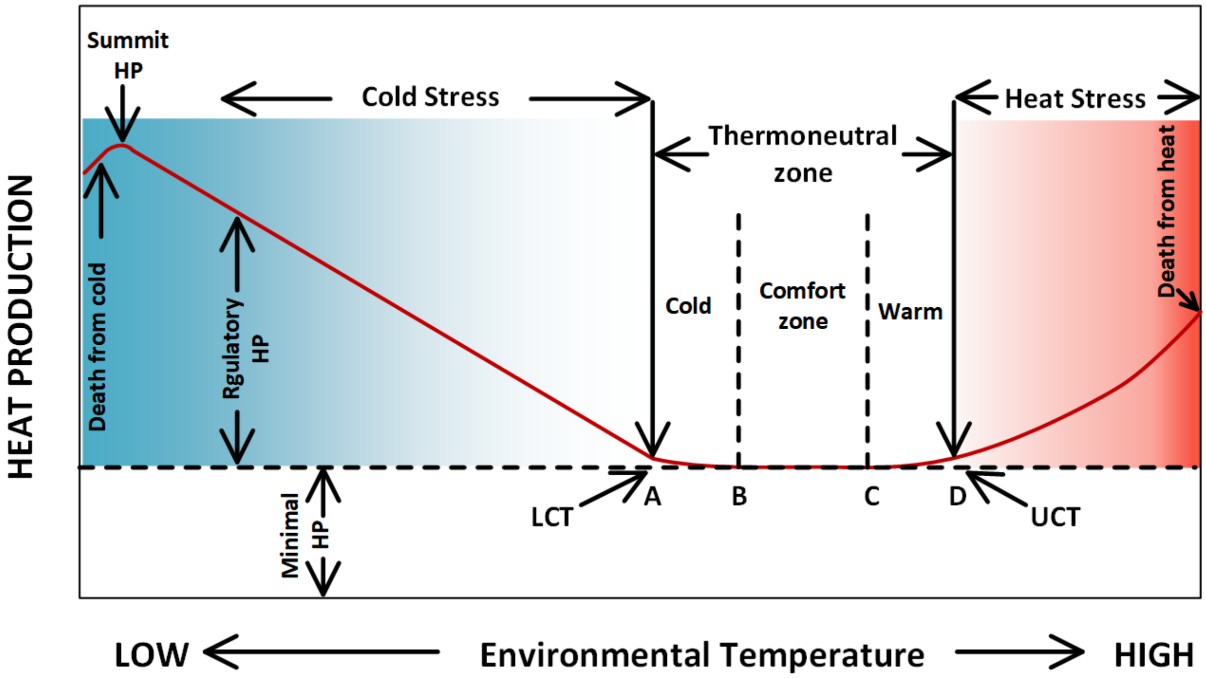

Figure. 3.1.1: The concept of thermal neutrality and thermal comfort (CT) (modified after Yousef, 1985). LCT=Lower Critical Temperature, UCT=Upper Critical Temperature; the red box marks the condition with heat stress; the capitals A-D are explained in the text below the figure.

Mount (1979) developed a general concept of thermo-regulation of animals which was modified by Yousef (1985) (Fig. 3.1.1). This modificated concept is based on a certain level of feed intake under stable or resting conditions. Within the temperature zone **A - D** pigs can keep their core 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 (Fig. 3.2.1), its breed, feed intake and environmental factors such as heat loss to the floor, air velocity around the animal, but also on motoric activity.

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

- Heat production below the LCT (**<A**, cold stress) can be increased by shivering (shivering thermogenesis) and by producing extra heat without shivering (non-shivering thermogenesis by activated energy metabolism).
- Within zone **A – B** (cool) heat loss can be reduced by behavioural changes, e.g. by huddling with other animals in the group to lower heat dissipation by body surface.
- In zone **B – C** (comfort zone) no effort is needed to balance heat loss with heat production. To compensate for the rising ambient temperatures, heat loss is kept at the same level mainly by lowering the skin resistance (vasodilatation).
- In zone **C - D** (warm) heat loss is regulated by behavioural, e.g. lying on cool places (e.g. slatted floor instead of insulated solid floor) or on wet areas to increase convective, conductive and evaporative heat loss (behavioural thermoregulation), and physiological changes, e.g. small increase of respiration rate.
- Above the UCT (**>D**, heat stress) high respiration rates and panting is shown as a sign of heat stress. Above point D, pigs will also lower their feed intake.

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 by increased respiration rate. At higher environmental temperatures, above the UCT, pigs show increased panting with more heavy abdominal breathing and a decreased voluntary feed intake. Furthermore, the effects of high relative humidity levels on pigs are expected to be more pronounced at high environmental temperatures (SCAHAW, 2002), because their evaporative capacity is limited. It becomes less pronounced if they can wet their skin by sprinklers or wallowing. Feed restriction increases the ambient temperature at which welfare is compromised due to heat stress. This is caused by feed intake as the main factor for heat production in pigs.

3.2 Implications of heat-stress

Above certain ambient temperatures, starting at approximately 22°C, clear physiological changes occur in finishing pigs (Brown-Brandl et al., 2001). The upper threshold level decreases with increasing body weight (Fig 3.2.1), e.g. for lactating sows, with a high feed intake, 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 feed intake and heat production, 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 disruption in Fig 3.2.1 around weaning will be lower at a higher weaning age because the solid feed intake and the body weight are higher.

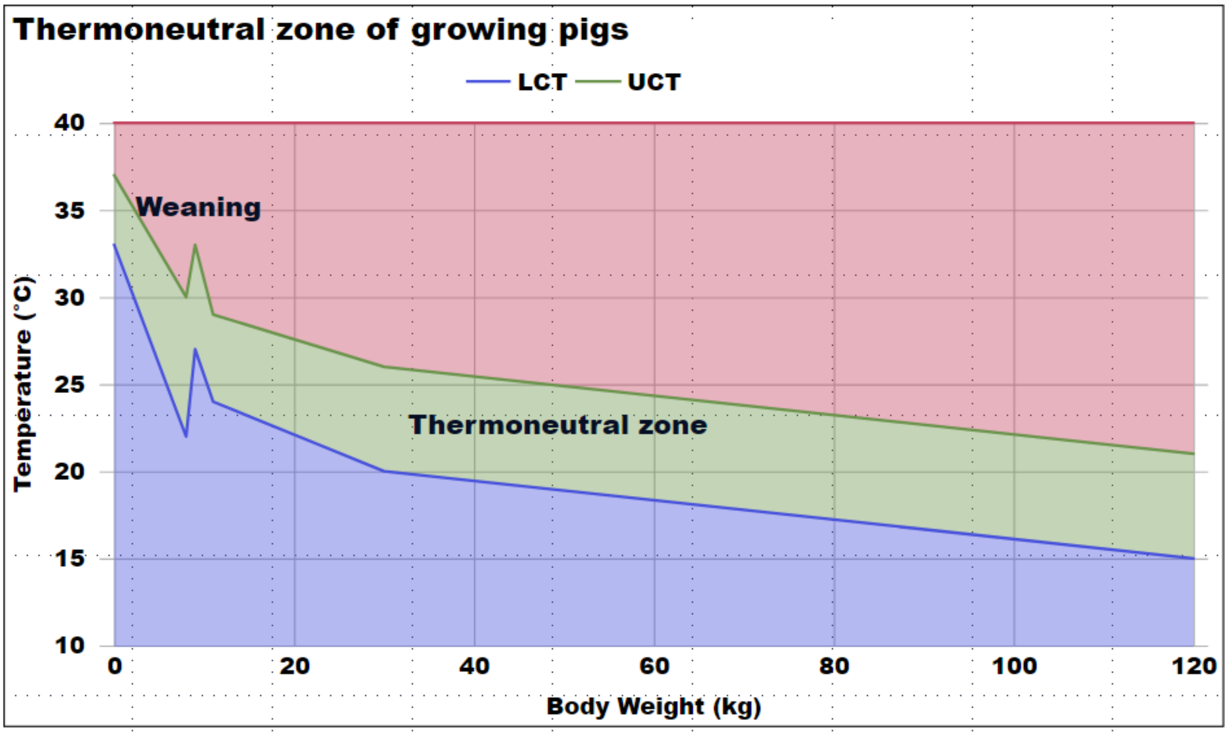

Figure 3.2.1: Schematic relation between thermoneutral zone and bodyweight; the red area indicates heat stress (Payola and Piriou, 2021)

The different strategies for heat dissipation are also based on different critical temperatures (Fig. 3.2.2). In order of appearance during rising ambient temperatures at first pigs are going to lie apart from each other, firstly they reduce huddling and then reduce physical contact. This is followed by increased lying on the slatted floor (instead of choosing an insulated solid floor), increased excretion on a solid floor, a higher respiration rate, a decreased feed intake and finally an increased rectal temperature.

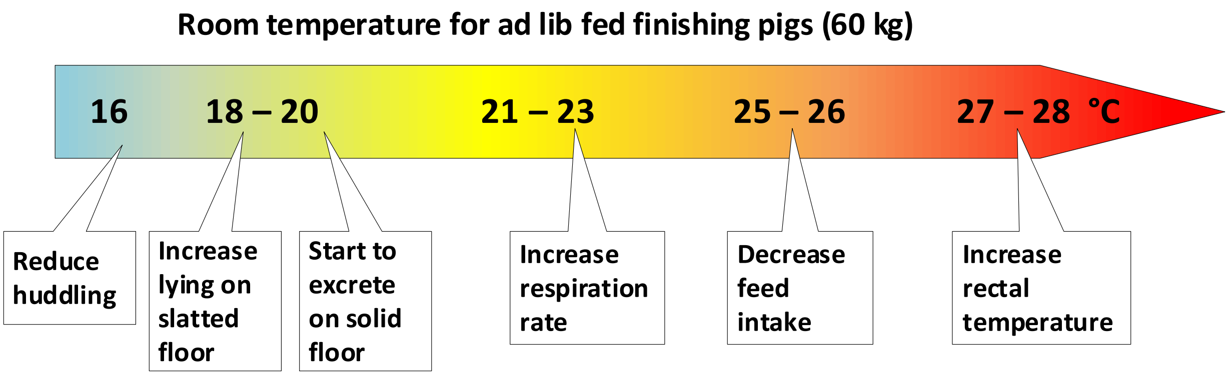

Figure 3.2.2: Chain of pigs' responses to increasing ambient temperatures (adapted after Huynh, 2005); the given temperatures are valid for an ad libitum fed finishing pig of approximately 60 kg.

3.3 Thermal requirements

The thermal requirements of pigs are depending on different factors. In Table 3.3.1 an indication is given of the upper limits of the comfort zone and the thermo-neutral zone for the different categories of animals. In housing systems with bedded or well insulated floors the limits will be lower.

Table 3.3.1: Indication of the upper limit of the comfort zone and thermo-neutral zone (in °C) of the different categories of pigs (Sterrenburg and Van Ouwerkerk, 1990).

Pig category	Upper limit **Comfort Zone**	Upper limit **Thermo-Neutral Zone**
Piglet 8 kg	31	35
Piglet 20 kg	26	30
Grower 30 kg	24	28
Finisher >60 kg	20	25
Empty sow	25	29
Pregnant sow	23	26
Lactating sow	18	21

4 Heat stress indicators to focus on during welfare inspections

When visiting a pig facility it is necessary to have a toolbox of indicators to detect heat stress. There are many indicators available, both environmental (risk factors) and animal based, of which some show an acute (skin temperature), others a longer term effect (pen fouling) of heat stress (Guevara et al., 2022). Different housing systems may have a strong effect on heat stress risk. A housing system is a combination of risk factors and will be described separately.

4.1 Environmental based indicators

Indoor temperature (T)
The air temperature indoor is the major environmental based indicator for heat stress. A temperature above the UCT (Figure 2 and Table 3.1) is a strong indicator of upcoming heat stress (Huynh, 2005). The temperature should be measured at pig level, and it is important to be aware that values can differ between locations within the pen and within the room.

Relative Humidity (RH) and THI
The water content of the indoor air determines the capacity of the expired air to “absorb” evaporated water from the pig (breath) and if possible also from the skin. The THI provides an index that combines indoor temperature and humidity [$THI=(1.8\times T+32)-[(0.55-0.0055\times RH)\times(1.8\times T-26)]$]. The higher the THI the more difficult it is to lose body heat (Figure 4.1.1). The THI is often suggested as a tool to assess the temperature-humidity combination in heat-stress risky situations. However, in non-sweating animals like pigs, the indoor temperature is the most important determinant for heat stress (Huynh, 2005).

As is valid for UCT every category of pigs needs it owns THI table (Fig. 4.1.1) with thresholds for T/RH combinations. However, specific porcine limits for different thresholds for different levels of heat stress were never developed. From a feasibility point of view more complex indicators (f.i. including air speed) were disregarded.

Relative Humidity (%) \ Indoor Temperature (°C)	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
0	54	56	58	59	61	63	64	66	67	69	71	72	74	75	77	79
10	54	56	58	59	61	63	65	67	69	70	72	74	76	78	79	81
20	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84
30	53	55	58	60	62	64	66	69	71	73	75	77	80	82	84	86
40	53	55	57	60	62	65	67	70	72	74	77	79	82	84	86	89
50	52	55	57	60	63	65	68	70	73	76	78	81	84	86	89	91
60	52	55	57	60	63	66	69	71	74	77	80	83	85	88	91	94
70	51	54	57	60	63	66	69	72	75	78	81	84	87	90	93	96
80	51	54	57	60	64	67	70	73	77	80	83	86	89	93	96	99
90	50	54	57	61	64	67	71	74	78	81	84	88	91	95	98	101
100	50	54	57	61	64	68	72	75	79	82	86	90	93	97	100	104

Figure 4.1.1: Example of Temperature Humidity Index for weaners of approximately 15 kg, based on Bracke et al., 2020 (legend: green=thermoneutral, yellow=early heat stress, orange=middle heat stress, red=severe heat stress)

Air cooling facilities

Cooling of the incoming air by a heat exchanger with cool water (e.g. from ground water) or by evaporative cooling by direct spraying of miniscule water droplets (fog/mist) in the air inlet or by cooling pads can lower the room temperature significantly (Häussermann et al., 2007). When moistening the air just before entering the building the indoor relative humidity will not raise to too high levels because of the increase in air temperature by the heat production of the pigs. Air inlet via underground tubes is also a robust cooling system (Godyń et al., 2020). The effectiveness of these techniques can only be assessed by comparing the outdoor temperature and the temperature of the fresh air entering the pig house.

Pig cooling facilities

Evaporation directly from the pig skin or a cool surface for conduction leads to a very effective way of heat loss. Wallowing in the manure in conventional pens can be functional but is not preferred by the pigs (Huynh, 2005). Cooling by evaporation can be realized by sprinklers (shower) and by conduction by floor cooling (Godyń et al., 2020). The use of showers significantly reduced pen fouling while simultaneous reducing ammonia emission by 43 % (Jeppsson et al., 2021) The absence of these cooling devices will increase heat stress.

Floor design
In housing systems with bedded or insulated floors without much slatted or wet areas pigs do not have opportunities for cooling during the summer (Fraser, 1985). In these systems heat stress develops already at lower temperatures.

4.2 Animal-based indicators

Increased respiration rate and panting (heavy breathing)
Increased respiration rate is one of the first indicators of heat stress. The breathing frequency (respiration rate per minute) can be counted by observing flank movements. Brown-Brandl et al. (1998) reported an increase in barrows from 20 at 18°C to 120 at 32°C, while sows increased respiration rate from 29 per min at 15°C to 58 per min at 25°C (Malmkvist et al.2012). According to the EU-PiG project (2020) a respiration rate above 50 breaths per minute at rest is an indication of heat stress. At more severe heat stress, forced expiration of breath (panting) is one of the possibilities for further evaporative cooling of the body. Another indicator related to panting during heat stress is the occurrence of open-mouth breathing (Kephart et al., 2010).

Skin fouling and skin colour
Pigs will start to look for cooler areas, e.g. the slatted or non-bedded floor, and wet areas to moisten their skin by lying or wallowing (Huynh, 2005). This will result in dirtier skins. Although a pig skin does not contain many superficial blood vessels and a layer of fat insulates the body, slaughter pigs can display skin discoloration (more red) during transport in the summer as a sign of heat stress (Ritter et al., 2008).

Pen fouling
Normally pigs excrete at a more or less fixed location inside the pen. At high temperatures, however, pigs are going to lie at cooler places and often these are the locations where they normally excrete. This causes fouling of the locations where they normally lie (Larsen et al., 2018). This fouling is generally very scattered at high temperatures, so often the whole pen is fouled with faeces and urine. This is a strong indication that the pigs are outside their comfort zone and experiencing more or less heat stress.

Skin temperature
The body surface temperature, which can be measured using infrared thermography, is another animal-based indicator to assess heat stress in pigs (Xiong et al., 2015), e.g. Malmkvist et al. (2012) found increased rectal and skin temperature at 25°C compared to 15°C in periparturient sows. Huynh (2005) mentioned 36 °C as a threshold for 60 kg pigs and found that sprinkling water on the pig body reduces both respiration rate and skin temperature. The core or rectal temperature would be a better indicator than skin temperature, but more difficult to obtain and only changing above the UCT.

Lying pattern: separated and in lateral position
During hot weather conditions pigs are lying down more frequently in lateral posture to increase conductive heat loss (Goumon et al., 2013). They minimize contact with pen mates (separated) and maximize contact with the floor (lateral position) to maximize heat loss. In case of partly slatted floors lying on the slatted area is a first indication of the room temperature approaching the UCT (Hillmann et al., 2004; Aarnink et al., 2006).

Reduced activity
At high temperatures pigs are less active (Huynh, 2005), e.g. sows showed less nest building pre farrowing and less standing and walking post farrowing at 25°C compared to 15°C (Malmkvist et al., 2012). Although pigs lie down most of the time, they generally become active when the farmer is coming into the room. When they do not become active in this situation, this is an indicator of heat stress but also of other possible problems.

Reduced feed intake
Reduced feed intake reduces metabolic heat production. Pearce et al. (2013) kept finishing pigs at 20°C (thermoneutral) and at 35°C (heat stress) and found a reduced feed intake of 50% in the heat stressed pigs, while Messias de Bregança et al. (1998) found reduced feed intake in lactating sows from 4.9 kg/day at 20°C to 2.8 kg per day at 30°C. Renaudeau et al. (2011) found in a meta-analysis a reduction of 30-60 g/d*°C between 25 and 30°C depending on body weight. Pig limit their meal sizes voluntarily to reduce high peaks of metabolic heat production.

Increased water intake/use
A higher water use, not all consumed but also used to moisten the skin and the floor, is an indicator of heat stress. An increasing ratio between water and feed intake is also a sign of heat stress (Huynh, 2005; Brown-Brandl et al, 1998). Malmkvist et al. (2012) observed increased water use in sows pre-farrowing when kept at 25°C compared to at 15°C room temperature.

The UCT's per animal category and to a lesser extend THI will be very helpful during inspections and temperatures (and humidity) and pen fouling are easy to measure/determine. The animal based indicators are more difficult to register and require sound protocols for scoring and thorough training. Individual indicators are not sufficient as a signal for heat stress, a combination of indicators is a better proof of heat stress and air quality (Vermeer and Hopster, 2018). Thus, from the list above we recommend ambient **temperature (T), relative humidity (RH), panting and pig fouling** as the most useful and proven indicators and will be described in more detail in indicator factsheets for heat stress.

5 Minimising welfare problems: improved practices

In this section we list some measures to reduce heat stress in pigs. The links to the sources with more details can be found in the reference list (Hoofs and Aarnink, 2021; EU-PiG, 2020; ILVO-Coolpigs, 2022). Plan and prepare measures several days ahead: Use weather forecast for outdoor temperature and humidity and check UCT (see Table 3.1) and THI with the heat stress table (see Fig. 5.1). Check indoor temperature and relative humidity regularly and compare them with the UCT and THI thresholds. Check pig behaviour (more lying apart, more lying on slatted floor, more pen fouling, more lateral lying, less activity).

5.1 Measures to reduce heat production

- Reduce feed ration before heat stress might occur: this will cost performance, but prevents mortality;
- Prevent arousal in the house during the hottest periods: adapted feeding times (Note: the farmer should not try to keep the same level of feeding by shifting the feeding time to cooler periods of the day, because this will prevent pigs from regulating their feed intake to prevent heat stress);

- Postpone treatments, to prevent arousal as in the previous point.
- Lower dry matter content of liquid feed by 1-1.5%.

5.2 Measures to optimize climate management

- Maximize ventilation rate;
- Use "ground tubes" for the inlet of fresh air, cooled by the soil.
- Use evaporative cooling of fresh air: water spraying (fog/mist) in the air inlet;
- Maximize space allocation per pig;
- Check drinkers (flow rate, fresh, clean, cool);
- Increase rate of showering if showers/sprinklers are present
- At heavily heat stress, directly spray water on the pigs and increase air velocity (circulation fans);
- Insulate windows or use white chalk; chalk or moisten the roofs (note: sufficient insulation of the roof is important to prevent solar heat from entering the pig house), but maintain sufficient light (>40lux);
- Be sure that the emergency system works in case of technical problems with the ventilation system;
- Clean ventilators, air ducts, air scrubbers and air inlet to reduce resistance;

6 Legal requirements

There are hardly climatic legal requirements for pigs in the EU-regulations. However, on a national level rules can be stricter, but often formulated as "open norms". Directive 98/58/EC states that the accommodation should "not be harmful" to the pigs, which can only be checked by animal based indicators given in section 4.2. However, legal limits are not available in most countries, with difficult enforcement as a consequence.

COUNCIL DIRECTIVE 2008/120/EC 3 (EU, 2008)
Annex I, Chapter I, Article 3: The accommodation for pigs must be constructed in such a way as to allow the animals to:
*- have access to a **lying area physically and thermally comfortable** as well as adequately drained and clean which allows all the animals to lie at the same time.*

Directive 98/58/EC (EU, 1998)

Annex: Buildings and accommodation
*Article 10: Air circulation, dust levels, **temperature, relative air humidity** and gas concentrations must be kept within limits which are not harmful to the animals.*

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EU Reference Centre for Animal Welfare *Pigs*

About EURCAW-Pigs

EURCAW-Pigs is the first European Union Reference Centre for Animal Welfare. It focuses on pig welfare and legislation, and covers the entire life cycle of pigs from birth to the end of life. EURCAW-Pigs' main objective is a harmonised compliance with EU legislation regarding welfare in EU Member States. This includes:

- for pig husbandry: Directives 98/58/EC and 2008/120/EC;
- for pig transport: Regulation (EC) No 1/2005;
- for slaughter and killing of pigs: Regulation (EC) No 1099/2009.

EURCAW-Pigs supports:

- inspectors of Competent Authorities (CA's);
- pig welfare policy workers;
- bodies supporting CA's with science, training, and communication.

Website and contact

EURCAW-Pigs' website www.eurcaw-pigs.eu offers relevant and actual information to support enforcement of pig welfare legislation.
Are you an inspector or pig welfare policy worker, or otherwise dealing with advice or support for official controls of pig welfare? Your question is our challenge! Please, send us an email with your question and details and we'll get you in touch with the right expert.

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