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1 Introduction

Pig meat production in the European Union (EU) is subject to Regulation (EC) No 178/2002 (the General Food Law Regulation), which provides an overarching guideline for food and feed legislation in EU member states. In the EU, the three main pork production countries (Spain, Germany and France) account for more than half of pork production. In general, a high density of farms is found with easy access to feed. Traditional pig farming using an agro-sylvo-pastural system is still followed in Spain. Among EU member states, pig farms are very different in terms of size and husbandry systems. In Romania, the country with

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most individual farms, there are both large farms, characterized by intensive production, and traditional backyard farms. Integrated production is common practice in Denmark and Spain, while it is not yet the case in other countries, such as Germany.

Modern pig husbandry systems are currently the focus of public and political attention in some European countries. There is focus on improving production of safe and high-quality pork using climate- and resource-friendly production systems that maintain high animal-welfare standards. Important recent drivers are EU regulations for sustainable production systems (e.g. Farm-to-Fork Strategy, New Green Deal, One-Health-Initiative) and higher animal welfare standards. Integral to these requirements is the transparency of the entire production chain backed up by appropriate documentation for both producers and regulators.

This chapter describes major husbandry- and management-related factors affecting health, welfare and production efficiency in different swine husbandry systems. Given the current transformation in pig production, there are several conflicting goals that need to be addressed during design and adaptation of husbandry systems in the future. After an overview of welfare and sustainability issues, the following sections deal with the most important areas impacting pig health and welfare such as space, climate, flooring, water and feed supply. Since it is not possible to give a comprehensive overview of all systems, the authors summarize fundamental housing requirements that must be achieved in all systems. They also review basic principles in assessing the quality of housing systems. The very important human factor is addressed at the end of the chapter.

2 Welfare and sustainability issues affecting pig production

There are different perspectives on the definition of good animal welfare. The World Organisation for Animal Health (OIE) and the European Food Safety Authority (EFSA, Panel on Animal Health and Welfare (AHAW)) define welfare as the 'ability of an animal to cope with its environment' (Broom, 1996). The five freedoms (freedom from hunger and thirst, freedom from discomfort, freedom from pain, injury and disease, freedom from pain and distress, freedom to behave in a normal and natural way) are defined as animal welfare prerequisites by the UK Farm Animal Welfare Council (FAWC, 2009) (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/319292/Farm_Animal_Welfare_in_Great_Britain_-_Past__Present_and_Future.pdf; accessed: 14.07.21).

Animal welfare is mainly impacted by husbandry conditions, management practices and the health status of animals. Welfare in farm animals is regulated

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by the Council Directive 98/58/EC and Council Directive 2008/120/EC, which lay down minimum requirements for husbandry conditions for pigs. The Commission had additionally adopted a Recommendation (EU) 2016/336 on the Council Directive 2008/120/EC, laying down minimum standards for the protection of pigs as regards measures to reduce the need for tail-docking. The EU-wide ban 'on the routine shortening of piglets' tails' (according to Annex I, Chap.I No.8 of Directive 2008/120/EC) requires pig farmers to implement an action plan to prevent tail-biting. Tail-biting has a multi-factorial origin. This requires significantly increased monitoring of abnormal behaviour to identify risk factors and keeping detailed records of husbandry and environmental conditions to identify potential triggers. However, conventional husbandry typically provides limited opportunities for pigs to express their natural exploratory and foraging behaviour. Boredom and frustration result in pathological behaviour patterns, such as tail, flank and ear biting or even vulva or penis biting, which are of great importance not only for animal health and animal welfare but also have important negative economic impacts.

The welfare of food animals is a growing concern. The ban of tail-docking in the EU is one important driver in re-thinking swine husbandry systems. An additional example is the requirements on the confinement of breeding sows, especially increasing space allowance, bedding and nesting material. These requirements have to be met by the farmers which, in turn, mean stall conversations and related investments with a high economic cost for many holdings.

The Directive 2010/75/EU sets out measures for environmental protection from emissions from intensive pig farms with capacity for more than 750 sows and 2000 fattening animals. To meet these requirements, the Commission Implementing Decision (EU) 2017/302 established best available techniques in the fields of nutrition, manure management and removal of dead animals. Water and air pollution are important environmental issues in pig production, mainly associated with manure processing. Important aspects are the introduction of nitrate (NO_3^-), ammonium (NH_4+), nitrogen (N), and phosphor (P) in surface and groundwater, emission of greenhouse gases (nitrous oxide (N_2O), carbon dioxide (CO_2), methane (CH_4)), acidification and air pollution by ammonia and nitrous oxide. Minimizing emissions requires measures such as adapted feeding strategies, no long-term storage of manure within the building, separate collection of solid feces and urine, emission-free storage of manure with solid flooring and a liquid manure collection tank, and covering of manure during storage. The vast majority of greenhouse gases result from feed production, while direct energy consumption is due to heating and ventilation. The European Green Deal Farm to Fork Strategy addresses sustainability of food systems with a particular focus on reduction of use of fertilizers, pesticides, antimicrobials and reducing biodiversity loss. It promotes a parallel increase in organic farming and animal welfare.

3 Fundamental housing requirements for pigs

Pig production systems differ in various ways, e.g. biosecurity, genetics, feeding system, bedding, flooring, ventilation, manure removal, group size, conventional versus alternative production, etc. The combination of those characteristics depends on different aspects, such as number of animals and level of production, geographic location (e.g. for outdoor farming), or if production must fulfil certain requirements (ecological farming, welfare labelling requirements). The housing system is the foundation for all measures and activities to guarantee the health, welfare and productivity of pigs, although the type of housing seems to be of less importance than the physical layout and how animals are managed by stock people (Hemsworth, 2018).

Pigs are usually kept in buildings with or without outdoor access. Minimal environmental requirements to guarantee welfare and health of pigs are set out by legislation (Table 1). The requirements for buildings address the:

- i optimization of climatic conditions, such as air temperature, humidity, velocity and direction of air flow, air contaminants such as dust and gases;
- ii the provision of adequate space for individual animals;
- iii guaranteed access to feed and water;
- iv the design of pens including flooring; and
- v technical and logistical solutions to remove manure.

Key requirements also cover the optimization of light and maximum noise levels (Zulovich, 2012).

Factors that influence the choice of housing systems include the provision and distribution of feed, space allocation, manure removal, as well as the distance from neighboring farms and frequently used roads. The location of a building within a particular geographic area can have a significant influence on its design and operation. An illustration of this is eradication of airborne diseases, which has a high risk of failure if the building is located in an area with high pig density, where infection in the pig population is endemic and filtration of incoming air is not practiced. Areas with high pig density are also a risk for other diseases, e.g. those that can be transmitted by rodents or other vectors able to move between neighbouring farms (e.g. transmission of *Brachyspira* spp, *Salmonella* spp.) (Desrosiers, 2011; Wang et al., 2011).

The location and design of a building has a major impact on welfare in the context of a future shift towards warmer climates. During hot weather, outdoor

Table 1 Summary of the minimum standards for the protection of pigs in general described in the Council Directive 2008/120/EC

	General Conditions
Accommodation	• Floors must be smooth but not slippery and suitable for size and weight of the pigs. • The lying area must be comfortable, clean and dry and allows all animals to lie at the same time. • Pigs must see other pigs.
Environment	• Continuous noise levels as loud as 85 dBA shall be avoided. • Light intensity of at least 40 lux for a minimum period of 8 h per day. • Environment must correspond to the needs for exercise and investigatory behaviour.
Feed	• All pigs must be fed at least once a day and pigs over 2 weeks of age must have permanent access to a sufficient quantity of fresh water. • When fed in groups, all pigs must have access to the food at the same time (exception: ad libitum feeding or feeding by an automatic system).
Health	• Aggressive, attacked pigs, sick or injured pigs are to be placed in individual enclosures.
Behaviour	• Pigs should benefit to their needs for exercise and investigatory behaviour. • Pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulative activities.
Allowed painful interventions	• Reduction of piglets' corner teeth and boars' tusks. • Docking of a part of the tails and castration of males (before the seventh day of life or after this age if carried out by a veterinarian and under anaesthesia and with additional prolonged analgesia). • Nose-ringing in outdoor husbandry systems. • The docking of tails or the reduction of corner teeth must not be carried out routinely.

and indoor climates are linked with solar irradiance on building surfaces having a significant impact on indoor temperature. Long, narrow buildings are cooler in summer and warmer in winter if the long axis runs from east to west. This is because the extent of solar radiation is reduced as a result of the large non-sunlit building surface on the north side of the building (northern hemisphere) or the south side (southern hemisphere) (Angrecka and Herbut, 2016). The pig shed should be situated to take advantage of prevailing winds for coolness in summer. Conversely, ventilation openings should be protected from prevailing winds in winter. Shelterbelts can affect the physical environment by effectively increasing the surrounding temperature in winter and reducing it in summer. Additionally, shelterbelts mitigate livestock odour and provide an aesthetic improvement to the landscape (Tyndall and Colletti, 2007). The eave width should be adapted in size so that the sun does not shine on the wall or into the interior of the piggery in summer, while the right width may also improve warming in winter. In confined livestock housing with forced ventilation systems (i.e. those relying on fans or blowers to circulate air in the pig barn), the exhaust air should be controlled to allow implementation of regenerative heat recovery as well as air purification.

Whilst some authors suggest positive effects of outdoor access for swine health and welfare compared to confined, indoor systems, there is a general recognition that both outdoor and indoor systems can have potential negative effects (Ludwiczak et al., 2021). There is also now an extensive literature on how far suitable enrichment in well-designed indoor settings can meet pig health and welfare needs (Düpjan et al., 2021).

Outdoor farming is only possible if regional soil and topographical requirements are fulfilled (e.g. sandy, well-drained soils). Outdoor farming systems are assessed to be beneficial in allowing pigs to display species-specific foraging behaviour typically with sufficient space to express this behaviour. Investment costs are also typically lower. Disadvantages include uncontrolled airborne emissions and seeping of manure components into the soil, high labor requirements and higher disease risk, particularly the lack of control of internal parasites. In outdoor farming systems, welfare and health issues differ significantly from closed systems. Sunburn in less-pigmented pig breeds is a common problem, other than mortality, due to predators such as owls and foxes. Biosecurity in outdoor settings is incomplete because birds, rodents and wild boars cannot be entirely prevented from entering the holding. Due to more limited opportunities for cleaning and disinfection, and the risk of soil contamination with pathogens, biosecurity can only be implemented to a limited degree (EFSA AHAW et al., 2021; Honeyman et al., 2003).

Organic pig farming in the EU represents about 1% of overall pig production. Based on the availability of land, soil characteristics, climate, tradition and national organic certification schemes, different housing systems have been developed, characterized by some access to a free-range area (Früh and Holinger, 2019). Organic pig husbandry systems can be divided into three types:

i indoor rearing with access to a concrete outside run;
ii outdoor farming with access to shelter; and
iii a mixed housing system with outdoor and indoor access during different production stages.

According to EU legislation, sows must have access to free-farrowing areas, farrowing units must provide a minimum area of $10m^2$, including an outdoor area of at least 2.3 m^2, whilst piglets must be suckled for up to 40 days before weaning.

In all housing systems, pigs must, at a minimum, be protected from extreme weather conditions and sunburn, always have access to a dry, comfortable resting area and always have access to water. Overall housing conditions, including pen design and stable equipment, should also not increase the risk for development of disease or trauma. Legal requirements for husbandry (e.g. in terms of feeding, animal handling or monitoring) must also be fulfilled. As well as minimal space requirements, EU and national rules also include regulations criteria for air quality. In addition, the needs of diseased pigs, which can be bullied by pen mates, must be addressed by provision of separate hospital pens allowing resting in a warm environment. The optimal ratio of hospital pens needed in a piggery is still under discussion (Millman, 2007, 2015). Animal needs can best be investigated by preference tests to determine those housing conditions which are most beneficial to animals (Elmore et al., 2010).

4 Behavioural traits to be considered in planning housing

Pigs were domesticated about 9000 years ago, but their natural behavioural patterns are still nearly identical to those of their wild ancestors. In wild boars, social groups are formed, which explore, eat, and rest synchronously and spend half of their active time foraging. Peak activity times are during the morning and afternoon hours, about 70% of which are filled with exploratory behaviour for the purpose of feeding. The results of choice experiments show that pigs can independently, relatively, and accurately select a balanced diet for themselves. They can also adapt the composition of their diet to meet changing requirements (Kyriazakis and Emmans, 1992; Kyriazakis et al., 1990). The pig thus has an intrinsic need for foraging and synchronous feed intake, which influences eating behaviour as well as the social structure in the group. This suggests that feed intake behaviour may be also influenced by external factors such as type of feed, feeding systems and housing facilities, health, breed and environment (Maselyne et al., 2015).

Conventional housing systems often do not meet those behavioural needs since they typically provide a complete, readily available high-energy feed at defined times. Intensive housing conditions are also often relatively sterile environments devoid of stimulation, thus depriving the intelligent pig species the possibility to exhibit their natural exploratory behaviour. The result can be manipulative or aggressive behaviour towards pen mates, which poses significant welfare, health and production challenges for pig farmers. Housing conditions are in interaction with the social hierarchy in a group and need to take account of social dynamics. It should be kept in mind that lower-ranking animals have better chance for adequate and stress-free uptake of feed and water, and also for a comfortable resting place, when a sufficient number of drinkers and feeders are installed in relation to the number of pigs and the pen provides enough space for resting behaviour.

Issues related to the visual, auditory, and olfactory abilities of pigs are increasingly the subject of research. It is known that there are large differences between individuals in terms of sensory perception and learning ability. Olfactory differences are generally learned faster than visual differences. In addition to operant conditioning in the sense of associative learning, pigs can learn olfactory and visual discrimination tasks (Croney et al., 2003; Gieling et al., 2011; Lind et al., 2007). Pigs, for example, can remember food locations and discriminate between different attributes of food (Mendl et al., 2010; Mendl and Paul, 2004). The pig´s hearing range exceeds the human hearing range. This means that loud and sudden noises can stress pigs. Noise can impact the ability of sows to react to their piglets and can interfere with the farrowing process (Chapel et al., 2019).

Pigs are able to make decisions based on visual information from a very early age. Curiosity and intrinsically high motivation supports the use of indirect visual information for novel foraging situations (Nawroth and von Borell, 2015). Conflicting data exist regarding visual acuity at low light intensities. At 12 lux, visual acuity was not impaired with respect to black and white discrimination (Zonderland et al., 2008). With respect to color vision, blue, in particular, is discriminated from other colors (Tanida et al., 1991). Choice experiments show that pigs prefer brightness over darkness, and infrared light is preferred in combination with heat (Baldwin and Meese, 1977). For pig housing, EU legislation requires 40 lux and German legislation 80 lux for 8 h per day. The natural circardian rhythm of the pig must be the basis for the light-controlled structuring of the daily routine (Tilger, 2005).

Pig behavioural traits can be assigned to ten functional groups:

1. Locomotion;
2. Feed intake (feeding behaviour);
3. Thermoregulation;
4. Explorative behaviour;
5. Reproductive behaviour;
6. Resting behaviour;
7. Excretal behaviour;
8. Body care behaviour;
9. Social behaviour; and
10. Birth-giving behaviour.

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All these functional groups are influenced by factors such as space, group size and pen structure. Housing and management conditions should, as far as possible, facilitate natural behaviour of pigs in all these functional groups. The degree to which this is prioritised depends on traditions and priorities in individual countries, which may change over time (e.g. due to economic pressures, disease outbreaks or changing political priorities). It is impossible to enable the full expression of natural pig behaviour in husbandry conditions other than for free-range pigs. Wild pigs with domesticated ancestors can still be found in some parts of Europe (e.g. Corsica, Sardinia) (Albarella et al., 2006; Jori et al., 2017).

The focus on enabling natural behaviour of pigs under farm conditions, as well as the need to comply with the ban on tail-docking (which increases the risk of tail biting resulting from aggressive behaviour), has led to an emphasis on enrichment to meet the basic behavioural needs of pigs. Enriching the environment for pigs with objects or substrates that 'enable proper investigation and manipulation activities' and which satisfy the pig's exploratory behaviour is required by law in the EU (Table 1). Specific requirements for enrichment are also defined in the Council Directive 2008/120/EC (Table 2). In principle, environmental enrichment should result in an increase in positive behaviour and a decrease in aggressive behaviour against pen mates and from engaging in stereotypic behaviours such as belly nosing and sham chewing, which are

Table 2 Sections of the Council Directive 2008/120/EC referring to enrichment materials for different age categories of swine (modified from van de Weerd and Ison (2019))

Directive Section	Age category	Text
Article 3 (5)	Sows and gilts	Member states shall ensure that, without prejudice to the requirements laid down in Annex I, sows and gilts have permanent access to manipulable material at least complying with the relevant requirements of that Annex.
Annex I, Chapter II: B3	Sows and gilts	In the week before the expected farrowing time sows and gilts must be given suitable nesting material in sufficient quantity unless it is not technically feasible for the slurry system used in the establishment.
Annex I, Chapter II: C.1	Piglets	A part of the total floor, sufficient to allow the animals to rest together at the same time, must be solid or covered with a mat, or be littered with straw or any other suitable material.
Annex I, Chapter II: D.3	Weaners and rearing pigs	When signs of severe fighting appear, the causes shall be immediately investigated and appropriate measures taken, such as providing plentiful straw to the animals, if possible, or other materials for investigation. Animals at risk or particularly aggressive animals shall be kept separate from the group.

ndicators of boredom or stress. However, since objects quickly lose their attractiveness through habituation, new and unfamiliar objects should be introduced regularly or a system of rotating enrichment objects should be implemented (Mkwanazi et al., 2019). The pig's natural curiosity is addressed by an unfamiliar object, thus stimulating the natural behaviour of investigating, manipulating it, and, potentially, concluding the interaction with reward feeding (van de Weerd et al., 2003). Straw is recognized as one of the most suitable materials for rooting and foraging behaviour, but it poses challenges for effective manure management (Pedersen et al., 2014).

It has been shown that stress affects the immune system via key hormones, such as corticosteroids and catecholamines. Corticosteroids lead to decreased proliferation of lymphocytes and antibody production, while catecholamines can affect the virulence of microorganisms, disturbing the balance between pathogen exposure and immune defence (Dalin et al., 1993; Lyte and Lyte, 2019; Lyte, 2016; Reiske et al., 2020). By reducing stress, enrichment can support immune function, so that, in addition to improved welfare by enabling rooting and avoiding aggressive behaviour, enrichment can play a role in preventing infectious diseases (Luo et al., 2020; van de Weerd and Ison, 2019; van Dixhoorn et al., 2016). Enrichment can reduce behaviour such as tail-biting and lead to higher overall growth rates due to better health (Carroll et al., 2018; Faucitano et al., 2020).

However, it is important to note that, for all their benefits, enrichment activities are not as important as overall management by farmers (Carroll and Groarke, 2019; Henningsen et al., 2018; Peden et al., 2019; Sørensen and Schrader, 2019). Enrichment activities can also be costly and time-consuming for the farmer to implement and maintain. Godyń et al. (2019) observed increased production costs, and lower farm output in farms providing enrichment. Most effective enrichment measures are expensive to manage (such as providing a regular supply of fresh straw), so that a significant reduction in injured pigs would be required to be profitable (Niemi et al., 2021). An animal-welfare program should financially support farmers to offset lower productivity. Cost-relevant health indicators are mostly not sufficiently improved by additional welfare measures, so that additional costs are not justified from an economic perspective (Tonsor and Wolf, 2019; Uehleke et al., 2021).

A legal obligation to provide environmental enrichment for pigs is not in force in all pork-producing regions. It is required by legislation in the EU, Switzerland and Norway, but, e.g. not in the USA or China (van de Weerd and Ison, 2019). In practice, enrichment is often not provided or is not adequate. Problems often observed on farms include the provision of hazardous material or objects or placing it incorrectly, in terms of reachability. In the future more emphasis should be laid on the economic benefits of effective enrichment (return on investment) as well as drivers for improvement, such as, e.g. benchmarking (van de Weerd and Ison, 2019).

5 Potential indicators for assessment of housing systems

The assessment and comparison of different systems and farms is hampered by the lack of robust and efficiently measurable indicators covering requirements in different areas (health, welfare, antibiotic usage, environmental impact and sustainability). The relationship between economic performance and animal welfare indicators has been found to be weak. Good farm managers can achieve high performance in both areas (Henningsen et al., 2018). Precise data collection on farms following the Welfare Quality® assessment protocol is expensive and time-consuming and therefore not used by many farms on a regular basis (Botreau et al., 2009; Temple et al., 2011). As a result, alternative ways of assessing welfare have been developed.

Roughly, two groups of welfare indicators can be distinguished:

- resource based; and
- animal based.

Indirect resource-based indicators (e.g. access to and consumption of feed) can help identify poor animal welfare conditions before animals are negatively affected (e.g. with reduced feed intake as a possible indicator of illness). Animal-based indicators are outcome-based indicators (e.g. relating to an animal's health status), which can be used to assess the interplay between housing environment, human–animal interaction and management as well as exposure to harmful microorganisms and abiotic stressors (EFSA, 2012). Researchers address animal-based welfare indicators in three different ways (Fraser et al., 1997):

- adequate biological functions (growth, reproduction, health);
- emotional state (no distress, fear, pain); and
- the ability to behave in a natural way.

An example of the two latter types of indicator, e.g. is stereotypical behaviour like bar-biting, which may suggest stress or boredom.

Different animal-based welfare indicators have been described for the collection of data (Table 3). An alternative approach to assess welfare is the use of data already available from routine inspections along the food chain (Nienhaus et al., 2020). Abattoir-based monitoring systems to assess the welfare status of pigs originating from specific farms are of growing interest (De Luca et al., 2021; Friedrich et al., 2020; Wadepohl et al., 2020).

Table 3 Indicators for assessing animal welfare on farms

Stages of production	Indicators	References
Sows	Ectoparasites, udder and teat lesions, claw alterations, frothy saliva	(Friedrich et al., 2020)
Piglets	Face lesions, carpal joint lesions, undersized animals, stereotypes	
Fattening pigs	Average daily gain, feed conversion ratio, treatment frequency, respiratory lesions, exterior lesions, animal management, and mortality	(Grosse-Kleimann et al., 2021)
Fattening pigs	Respiratory health: pneumonia, pericarditis, pleurisy animal management: milkspots (liver), intestinal alterations, whole carcass condemnation, dermal damage (handling) external injuries/alterations: tail lesions, bursitis, ear lesions, dermal alterations Salmonella status, antibiotic usage, mortality	(Nienhaus et al., 2020)
Fattening pigs	Bursa alterations, lameness, dirty animals, runts, and tail, flank and ear biting	(Wadepohl et al., 2020)

A key problem in using data across the food chain to assess welfare is data availability and access to databases which differ along supply chains as well as between countries and regions. Poor availability, quality and interconnectivity of data in many areas of livestock production may be due to the relatively late adoption of information technologies in this field (Faverjon et al., 2019). Large quantities of data are generated at all stages in the pork-production chain, but combining it using big data approaches is still largely restricted to the occasional pilot project (Faverjon et al., 2019). Sterchi et al. (2019) highlighted the role of pooling data to assess the effect of shared transport and truck contamination on disease transmission between farms. In a German pilot study, the lack of interconnectivity between data bases and the incompatibility of data formats were overcome using a relative scoring approach. Z-transformation of different variables from different data sources was used to generate an animal health score that allows comparison and benchmarking of farms (Table 3) (Nienhaus et al., 2020). Grosse-Kleimann et al. (2021) conducted a comparable study based on production data for German finishing pigs (Table 3), indicating that the health indicators examined are usable for welfare monitoring.

In the EU, animal carcasses are sent to rendering plants, providing a continuous flow of mortality data, which could be used for farm monitoring. Mortality can be considered as one of the most important animal health indicators, making it particularly important to record this parameter consistently in a database (Lopes Antunes et al., 2017). Monitoring of mortality rates in combination with antibiotic usage data was found to have a predictive value in forecasting infectious disease on farms (Lopes Antunes et al., 2019). So-called 'iceberg indicators' might be helpful to assess welfare, health, management and productivity on farms to evaluate and improve housing and management systems. Ice-berg indicators need also to be developed to include the carbon footprint as well as emission and resource use data.

6 Housing requirements: climate, ventilation, temperature and air quality

6.1 Climate and ventilation

Indoor climate is influenced by a wide range of factors, such as the external environment, building type and age, building materials, insulation, ventilation system as well as stocking density (Banhazi et al., 2008). Concrete as a building material can retain heat and be warmed up if dry, though damp concrete flooring accentuates the negative effects of low temperatures. Indoor climate quality can be measured by variables such as air temperature, humidity, air velocity and pollutant gas concentrations (CO_2, NH_3, H_2S). Measuring and managing climate requires a fundamental understanding of the relationship between humidity and temperature as well as algorithms to measure different aspects of air flow. A particular problem is rapidly changing weather conditions, which cannot be quickly compensated by indoor ventilation equipment.

The most important climatic stressors affecting pigs are draught and incorrect temperature. Intermittent draught has been shown to initiate sneezing and coughing. Air speed should be below 0.15 m/s at pig level (Scheepens, 1996). In general, a relatively hot and humid environment is considered beneficial, resulting in less coughing (Geers et al., 1989; Gordon, 1963). As well as temperature, air quality is important. Several air contaminants damaging the lungs have been detected at the slaughterhouse stage (Cargill et al., 2002; Donham, 1991). Under the so-called 'sweet house' conditions, harmful airborne particles in the range of <1–3 μm are reduced (Thomas, 2013). Good cleaning regimes influence air quality, e.g. the removal of sediment dust from new pigs before they enter the barn. In case of infectious respiratory diseases, the ventilation system should be monitored using sensors for variables such as temperature, air velocity, circulation and impurities (Gonyou et al., 2006). Slurry levels in pits below the slatted floor of pig barns must also be controlled since surfaces closer than 40 cm to the slat bottom increase the risk of releasing bacteria-containing aerosols.

Independent of the environmental conditions, a minimum amount of fresh air (depending on the number and age class of pigs) must be introduced regularly into a building to remove bacteria, water vapour, carbon dioxide, ammonia, airborne dust and odour. Uncontrolled air exchange via damage to building walls must be avoided. Cold air must be warmed to avoid draughts. In this respect, natural ventilation has been found to be inferior to forced ventilation systems with regards to the levels of NH_3 and CO_2 as well as thermal comfort, resulting in higher risk of respiratory disease (Chantziaras et al., 2020). This is partly because animal density (measured in kilograms of swine per cubic meter) is correlated with the degree of airborne contamination, with forced ventilation more efficient in adjusting for higher densities (Donham, 1991). Practitioners recommend an air volume of more than 3 cubic meters per finishing pig not heavier than 100 kg (Marco et al., 2020). High animal density in confined livestock buildings requires mechanical ventilation systems to ensure adequate air quality and temperature both in summer (at high ventilation rates) and in winter. Ventilation in general will reduce temperature so that insulation of roof and walls is important to minimize heat loss and draught. Insulation combined with a vapour barrier can reduce condensation and therefore the need for ventilation. Failure of a ventilation system in a confined system can be fatal with rapid changes in temperature potentially leading to heat shock and dehydration or hyperthermia. Airspace stocking densities of 2.5 m^3/grower and 3 m^3/finisher are recommended (Gonyou et al., 2006).

6.2 Temperature

The optimal temperature range for pigs is defined as the thermoneutral zone (optimising productivity, health and welfare) (Zulovich, 2012). Within this temperature range, heat production by the pig itself is not influenced by air temperature. Lower and higher temperatures beyond body-weight-specific thresholds can have increasingly negative effects. Below the lower critical temperature, homoeothermic conditions will be maintained by increased metabolic activity. Above the upper critical temperature, pigs will try to dissipate heat but are at serious risk from heat stress. Absolute critical temperatures depend on feed intake, age, weight and environment. To assess the effects of a housing system, the temperature humidity index (THI) can be used to quantify potential heat stress in pigs (Wegner et al., 2016). The THI combines air temperature and humidity whilst taking heat release into account. In summer, high temperatures and a high THI around insemination reduce litter sizes. These conditions around farrowing reduce numbers of liveborn piglets, while numbers of weaned piglets are not affected (Wegner et al., 2016). Older pigs can tolerate low temperatures when they are not exposed to draught.

Observing pig behaviour will identify inadequate temperatures. Shivering and huddling behaviour indicates that the temperature is too low. Avoidance of skin contact between pen mates and fouling additional areas, which are normally clean, indicate that temperatures may be too high. Since swine cannot sweat and heat dissipation under natural conditions is mainly achieved by changes in behaviour (e.g. wallowing), pigs are particularly vulnerable to heat stress. Heat transfer is influenced by air-vapor mixture. Sensible heat transfer needs a temperature difference between two surfaces whilst latent heat transfer is mediated by differences in moisture concentrations (Deshazer et al., 2009). Where there is direct contact between surfaces of different temperature, conduction of heat from the warmer to the colder surface will occur, mediated by velocity of air circulation. At temperatures lower than 18–20°C pigs prefer a solid floor while, above 20–25°C, a preference for lying on slatted floor (for thermoregulatory reasons) is observed (European Food Safety, 2005). It is important to be aware of different sources of heat and mechanisms of heat transfer which can counteract each other e.g. cold flooring leads to heat conduction, while heating lamps provide radiated heat.

Extreme weather events involving higher temperatures will become more frequent due to the effects of climate change and will be a significant challenge because most housing systems have insufficient cooling mechanisms in place. Initial measures to deal with this problem include removal of heat sources, avoiding stressful handling of stock and moving feeding to cooler periods (night). Buildings can be cooled by spraying water on the roof surface. A very effective means to reduce temperature is reducing stocking density. In the long run, the housing system should be equipped with additional cooling systems together with increased ventilation. Evaporation through spraying water can reduce temperature. However, installing such equipment means high investment and energy costs, which may not be economically or environmentally sustainable over time.

There are various ways of optimizing the efficiency of cooling systems. The thermodynamic properties of the inlet air can be influenced by evaporative cooling pads (Xuan et al., 2012), earth-air heat exchanger (Bisoniya et al., 2014) or an indirect evaporative cooling system combining both and avoiding air humidification (Heidarinejad et al., 2009). This last system cools inlet air by evaporation, which is subsequently used in an air-to-air heat exchanger (ASHRAE, 2008). All three air treatment devices are valuable adaptation measures but need significant capital investment (Olesen and Bindi, 2002). Heat exchangers are effective for cooling in summer as well as higher and more stable temperatures in winter, allowing a higher ventilation rate, which improves air quality (Vitt et al., 2017).

6.3 Air quality

As noted earlier, natural ventilation has been found to be less effective than forced ventilation in reducing levels of NH_3 and CO_2 (Chantziaras et al., 2020).

Indoor air quality, as defined by gaseous and particle components, is mainly influenced by ventilation and the system for handling manure, which is itself influenced by feed composition and barn and pen design. Particulate matter (PM) in stable air is a mixture of particles of different size and biological and chemical properties (Cambra-López et al., 2010). PM10, PM2.5 and PM1 define particles of which 50% pass a size-selective filter of 10 μm, 2.5 μm and 1 μm aerodynamic equivalent diameter (Ulens, 2015).

PM stay in the air when interaction with air molecules is stronger than gravity. PM can bind and carry noxious gases like ammonia and, after inhalation, will deposit (PM smaller than 100 μm) in the upper airways (<10 μm), or in the lung (<4 μm). In general a concentration of 2.4mg dust per m^3 should not be exceeded in confined conditions due to health hazards for human and swine (Donham, 1991). Humidity has been found to affect PM (Kim et al., 2008). This means absolute humidity should be as high as possible to reduce air-borne particles but relative humidity must not exceed 80%. A promising method for reduction of airborne particles is spraying oil or an oil-water mixture in buildings (Pedersen et al., 2000).

In general, carbon dioxide is a good indicator for the effectiveness of ventilation and air quality (Donham, 1991). High levels of CO_2 (>2000 ppm) indicate inadequate ventilation rates, which should guarantee an air exchange of 60 m^3 per hour and pig (Flesjå and Solberg, 1981). Ammonia concentration is another measure of air quality. Legal thresholds are usually defined at 20 ppm but 10 ppm is considered to be the maximum gas concentration to ensure no adverse effects from ammonia. Several factors affect ammonia concentration in swine buildings, including manure and feeding management, hygiene, animal age, stocking density, season and ventilation. A decrease in ventilation rate at night causes an increase in ammonia concentration (Rodriguez et al., 2020).

7 Housing requirements: pen design, group size, feed systems and flooring

7.1 Pen design

Pen design and arrangement varies between individual farms and should be based on good animal observation, so each behaviour has a functional area in the pen in which it can occur (feeding, activity, lying, defecation), taking into account social interaction in each functional area. Synchronous access to water and feed would meet pig needs best but is hard to achieve with no 1:1 pig-feeding place ratio in conventional systems. The floor space required depends in part on body weight. Space requirements for weaner or rearing pigs according to weight are given by Council Directive 2008/120/EC (Table 4).

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Table 4 Recommended minimum unobstructed floor area available for weaner or rearing pigs kept in a group and the calculated constant *k* based on the maximum weight according to Council Directive 2008/120/EC

Live weight (kg)	m^3	Constant k $k = \frac{A}{BW^{0.67}}$
Not more than 10	0.15	0.032
More than 10 but not more than 20	0.20	0.027
More than 20 but not more than 30	0.30	0.030
More than 30 but not more than 50	0.40	0.029
More than 50 but not more than 85	0.55	0.028
More than 85 but not more than 110	0.65	0.027
More than 110	1.00	

The floor size specified by EU regulations cannot be considered as optimal. For better health and productivity outcomes, approximately 20% more space per pig has been recommended (Hamilton et al., 2003). In general, more space, and thus a lower animal density, can reduce the risk of transmission of pathogens and disease. A compromise must be found between stocking densities that do not impair animal health but are adequate for a sufficient return on space investment costs.

The resting area should be designed so that pigs passing to activity areas do not disturb their pen mates. A ratio of 1.5:1 to 2.5:1 is recommended for nursery and fattening pigs. Different flooring areas can either reduce heat conduction (e.g. plastic, solid floor) as well as increase heat conduction (e.g. concrete slatted floor, metal or wet floor). In high air temperatures sufficient space for pigs to lie in a fully recumbent position to dissipate heat is crucial. Space requirements should account for those demands (Carol Petherick, 1983; Corino et al., 2003; Ekkel et al., 2003; Pastorelli et al., 2006). Lying behaviour is not only affected by temperature but also by the floor type. Ekkel et al. (2003) suggested reducing space allowance in slatted systems by factor of 0.003 because pigs typically lie closer together in these conditions. In deep-litter housing systems, at least 30% more floor space per pig is recommended (Ekkel et al., 2003).

The lying area should preferably be quiet and dark, avoiding travel routes to other locations, but ideally with enclosed corners. Space for defecation should be at least 0.08 m^2 per animal independent of the whole space. Ideally 20–30% of the overall space should be provided for defecation in a pen. Additional space next to defecation and resting areas can serve as an activity area. Efficient space utilisation without adversely affecting welfare should be the goal of successful pork production (Anil et al., 2007).

7.2 Management of group size

Deciding on group size will be mostly influenced by the overall herd size and the feeding system. In smaller groups, locating individual animals and performing routine management tasks like pregnancy and estrus management are easier because of smaller pen space and the reduced number of animals. In small groups, synchronous feeding of all swine is feasible while meeting the nutritional needs of the individual after sorting by size and age. In sow herds, static grouping mostly results in small groups. Housing in small units facilitates use of the 'All In All Out' (AIAO) system.

'Large group size' is a relative term that can range from 50 to several hundred pigs per group. The advantages of large groups are the more efficient use of labor, space and pen divisions. In larger groups, observation and treatment of the individual pig is more challenging. New technology can make a significant contribution to managing large groups effectively, e.g. the electronic sow feeder (ESF) system where individual sows are identified by transponders in ear tags. These allow a computer-controlled feeder to allocate a specific amount of feed to each sow and can be used to monitor animal movement and feed consumption (e.g. by identifying sows that have not accessed the feeder).

Group size related to space is a relevant factor for health. Large numbers of animals in a group can lead to a higher frequency of fights to establish ranking order, but may also decrease aggression due to more opportunities to avoid dominant animals (Samarakone and Gonyou, 2009; Turner et al., 2003). To maintain social stability, it has been suggested that each pig within a group should be able to recognise every other pig and their relative social status. It has been estimated that pigs can recognise between 20 and 30 individuals (Fraser and Broom, 1990; Broom and Fraser, 2015). Turner et al. (2001) combined unfamiliar pigs from small and large groups and found that pigs from large groups showed a marked reduction in aggression towards unfamiliar pigs (Turner et al., 2001). Large groups facilitate avoidance or escape as well as formation of subgroups, reducing chances of aggressive interactions. The overall goal of an optimal pen structure is to allow every pig to fulfil its needs at all times without hindrance. Space and structure should guarantee resting times with deep sleep as well as opportunities for play and exploration. Contact with feces and urine should be avoidable, suggesting use of areas of slatted flooring in most systems. Devices or measures to avoid heat stress should be implemented.

7.3 Feeding systems

Pigs' feeding behaviour is controlled by hunger and satiety, but can be influenced by a range of other factors, such as type of diet, housing system,

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breed and health (Maselyne et al., 2015). Feed management must meet varying nutritional needs throughout the production process (lactation, reproduction and growth). Poor access to feed results in uneven and reduced growth and body condition, a poor feed conversion rate and an increased percentage of downgraded pigs. Trough feeding is generally considered to be better than feeding from the floor. Trough construction should prevent pigs from getting inside the trough, lying or defecating in it.

Pigs want to eat synchronously, which is attainable with an animal to trough space ratio of 1:1. But the available number of feeding places varies according to feeding system (ad libitum or rationed). Single-space or multi-space feeding systems can be combined with wet and dry feeders. Group size is oriented to feeding systems, with 25 pigs per mush feeder, at least 25 pigs per liquid feeding system and a maximum 25 piglets in a dry feeding system. The larger the group the higher the animal-feeding-place ratio (1:3 to 1:4). Feeder space sizes ranging from 0.15 m per pig (8 weeks of age) to 0.3 m per finishing pig and 0.45 m per sow are often too small and do not account for pigs' competitive eating behaviour. Slow growing pigs in particular seem to benefit from more feeder space (He et al., 2018).

The provision of safe and palatable water in sufficient amounts at the right temperature is essential to pig health and welfare. The number of drinkers depends on group size, but at least two drinkers must be installed in a pen so that they cannot be blocked by dominate pigs. Wet flooring risks pigs choosing the drinking area for defecation. More water is wasted by push-type nipple drinkers but they can be used to wet skin for cooling during hot weather. Waste water can be reduced by correct mounting of drinkers. While straight-out-pointing drinkers should be in the height of the smallest pig´s shoulder, drinkers at an 45° angle downwards should be 5 cm above the pig's back (http://www.omafra.gov.on.ca/english/livestock/swine/news/mayjun12a1.htm, accessed: 24.09.2021). Within the thermal comfort zone, drinking behaviour usually occurs within 10 minutes of eating (Gonyou, 2001). Diseased pigs show a different drinking behaviour from healthy pigs even in the subclinical stage of infection. If water usage drops about 30% on 1 day or is obviously decreased on three consecutive days, a health problem can be expected in the herd. Consequently, automatic monitoring of feed and water intake can provide early warning of disease or stress (Maselyne et al., 2016).

7.4 Flooring

In the case of slatted floors, flooring material as well as slat and gap width must be adapted to the pigs' claws size to avoid injuries. The maximum width of the openings and minimum slat width is set out by EU Directive 2008/20/EC (Table 5). In general, a pig's claw should not fit into gaps. The slat opening

Table 5 Recommended maximum width of the openings of concrete slatted floors and minimum slat width for different age categories of swine kept in groups according to Council Directive 2008/120/EC

Age category	Maximum width of the openings (mm)	Minimum slat width (mm)
Piglets	11	50
Weaners	14	50
Rearing pigs	18	80
Gilts after service and sows	20	80

should be uniform along its whole length to prevent claws becoming trapped if the gap narrows. The width should not be larger than half the width of the claw-floor-contact area (European Food Safety, 2005). A maximum 60% of gaps (in relation to the total contact area) for weaners with 8 kg body weight (bw), 51% for finishers of 100 kg bw and 40% for heavier pigs are considered beneficial for welfare and health (European Food Safety, 2005). Claw lesions and lameness are caused by inappropriate slat and gap width, wetness and dirtiness of the floor. Good flooring must be smooth and non-slippery, dry due to quick drainage and easy to clean. Concrete slats should have rounded edges and no sharp cuts or cracks, which might cause claw injuries. Deterioration of concrete floor, e.g. by cleaning procedures, which results in a rough surface, can cause injuries to claws and legs as well as infection. The roughness and hardness of flooring affects hoof abrasion. In general, abrasion should outweigh horn growth, avoiding both overgrown hooves and abrasion of soft hind claws. Other materials, like plastic and cast iron, are more slippery, but are warmer for the pigs to lie on.

Partly or fully slatted floors can be kept clean more easily than solid concrete floors. Where solid floors are used, efficient drainage is essential. A solid floor can become very contaminated, especially if ventilation and airflow are poor. In general, to prevent fouling it is important to ensure the right climatic conditions in lying areas (Larsen et al., 2018). Dust, gaseous emissions and airborne bacteria can be reduced using effluent channels in which manure is submerged in water. In partly slatted flooring systems, the minimal slatted area must be increased where the temperature is above 25°C and with higher stocking density. An appropriate proportion can be 40% or more, depending on both parameters (European Food Safety, 2005). Reducing the surface area, e.g. by lower width of slats, can reduce fouling and NH_3 emissions (Aarnink et al., 1997).

Deep bedding with material such as straw, sawdust, wood chips or peat usually requires a solid concrete floor. Bedding material provides the pig with physical and thermal comfort. Since it encourages rooting and foraging behaviour, it increases animal welfare. In managing bedding material, it is crucial to avoid high humidity and ammonia emissions, exposure to dust, as well as risks from mycotoxins and pathogens in the material. For any system providing bedding, costs will be increased by the need for composting or disposal.

Fresh straw as bedding material should be provided every 2–3 days. Damp straw, soaked with urine and faeces, soften the claws and increases the risk of claw infections (Maes et al., 2016). In fattening units, manure is usually not removed until slaughter. In cold conditions deep-litter bedding with straw or compost will provide thermal comfort. However, in warm conditions bedding produces a large amount of heat, increasing the risk of thermoregulatory problems. In so-called 'sloped manure confinements,' an inclined solid floor area with an approx. 6% slope is combined with access to bedding material in the upper side, which can be used by the pigs. Manure is collected on the lower side of the pen and can be removed automatically. This combination results in low emissions and a good microclimate. Other systems have a separate bedded area for lying and a bare area for defecation, which can have slatted or solid floor. Bedding in general requires more space and additional work to deal with dung.

8 Specific housing requirements for sows and suckling piglets

8.1 Sows

Three housing requirements are considered important for the health and welfare of sows:

1. Environmental enrichment for gestating sows to extend feeding and foraging times as well as to improve satiety.
2. Escape opportunities in group-housed sows to reduce aggressive behaviour.
3. Opportunities for nest-building behaviour and movement for farrowing and lactating sows

For groups of gilts, there needs to be sufficient space to support attaining puberty. Levis (1997) published the formula: $A\ (m^2) = 0.036 \times BW^{0.66}$ to assess minimum floor space for gilts.

8.2 Pregnant sows

About 75–85% of breeder sows in an intensive farrowing farm are kept as gestating sows, with the percentage depending on the length of lactation.

According to the Directive 2008/120/EC, gestating sows should be kept in groups up to 4 weeks after service to 1 week before the expected time of farrowing. Changes in farrowing crate regulation are expected in the near future and the time period for sows kept in crates will be reduced to a minimal number of days around farrowing and insemination.

One advantage of using crates is protection from aggressive behaviour, which is a particular issue during the first weeks after insemination. Individual housing also makes it easier to monitor health and tailor feeding to ensure optimal body condition. However, crated sows can suffer from problems such as urinary tract infections, overgrown hooves, and stereotypical behaviours resulting from confinement, including bar-biting, head-weaving, and sham-chewing. On the other hand, loose housing is often associated with problems such as lameness, foot and other diseases such as cystitis and pyelonephritis, particularly if floors are not kept clean and dry (Calderón Díaz et al., 2014). Slipping or foot disorders in sows can increase crushing of piglets (Calderón Díaz et al., 2014; Fitzgerald et al., 2012).

Group housing allows freedom of movement and social interactions. The number of sows in each group can vary greatly in size from less than 10 sows to hundreds. The optimum group size for pregnant sows has yet to be determined (Anil et al., 2006). Space requirements in group housing of sows are determined in the Council Directive 2008/120/EC (Table 6). The main source of stress is competition for resources so groups should ideally have synchronous access to feed and a comfortable resting area. Electric sow feeder systems (ESF) are frequently used in group housing systems for pregnant sows. Whilst they allow individually-tailored feeding, they can cause competition between sows (Jang et al., 2017). ESF should protect the sow inside the automated feeder box to prevent potential aggression. Low-ranking sows were found to be at a disadvantage in both static and dynamic groups, being subject to more aggression and injuries and poorer productivity compared with high-ranking sows (Bench et al., 2013). Sows should be provided with fermentable fibers in the diet to improve satiety.

Sow groups can either be stable, which means the group does not change, or may be dynamic, with sows leaving and entering the established group

Table 6 Space requirements for sows and gilts kept in groups according to Council Directive 2008/120/EC

	Area in square meters		
	Group size: up to 5 animals	Group size: 6–40 animals	Group size more than 40 animals
Gilts	≥1.80 m^2	≥1.64 m^2	≥1.48 m^2
Sows	≥2.48 m^2	≥2.25 m^2	≥2.03 m^2

multiple times. When sows are re-grouped after weaning or after insemination, increased aggression occurs due to establishing hierarchies. Full integration of small groups of gilts or sows in large dynamic groups may last 3–4 weeks, with the day of introduction producing the highest level of aggression (Spoolder, 1998). Pre-exposure in a separated area in the same room allows visual, olfactory and auditory perception of future pen-mates, which can reduce later fighting. Sustained aggression may be caused by competition for resources. Aggression can be more severe in circular compared to rectangular pens, as pigs prefer corners to hide from other pigs (Wiegand et al., 1994). In general, solid pen barriers can reduce aggression in group-housed sows. In large, dynamic sow groups, solid barriers can be used to create lying pens for sow subgroups. In general, escape opportunities must be provided to reduce aggression and minimise risks of injuries and stress.

8.3 Farrowing and lactating sows and suckling piglets

While there is no specific space allowance for farrowing pens in current EU regulations, 2.79 m^2 is recommended during farrowing and lactation by Baxter et al. (2011b). Twenty-four hours prior to farrowing sows exhibit nest-building behaviour with a peak 6–12 h before farrowing (Andersen et al., 2014). Sows showing intense nest-building activity are thought to be more maternal with less risk of crushing piglets (Iempeng et al., 2019). Maternal traits in combination with housing conditions are major factors in pre-weaning mortality. Pen design can reduce the number and type of crushing events, particularly when sows lie down or roll over (Baxter et al., 2011a). Providing sows with bowls will facilitate water uptake in comparison of nipple or press level drinkers, reducing the risk of conditions such as cystitis-pyelonephritis (Stalder et al., 2010).

Currently the vast majority of farrowing sows in the EU are housed in farrowing crates to allow safe handling of sows and piglets and minimize the risk of crushing. In future the number of days when a sow is confined around farrowing will be kept to a minimum of approximately five days. Research suggests a crate size of approximately 200 cm width × 280 cm length (Pedersen et al., 2013). Many crates are too narrow to allow adequate space for getting up and lying down. Crates must also be adjustable to differing sizes of sow to allow sufficient but mot excessive movement. Space for piglets requires approximately 56 cm to both sides of the sow for suckling as well as a lying area large enough to allow synchronized resting.

Research suggests that free-farrowing pens that do not confine the sow may be superior in terms of lower stillbirths, increased colostrum intake by piglets as well as fewer injuries, though devices such as farrowing rails are needed to protect piglets (Verhovsek et al., 2007; Kilbride et al., 2009a). Pens for free farrowing should be divided into a dedicated lying area separated from an area for defecation. About 50% of the floor should be solid to allow nest-building behaviour with adequate material. The slatted area at the rear of the pen should be long and wide enough (longer than the sow) to allow the sow to distance herself from the feeding trough. Floor plans can be found in various publications or on the website of the FreeFarrowing Project (www.freefarrowing.org, access: 22.9.2021). Pens are often equipped with sloped walls to assist the sow in lying down. Pens should include creeps (areas accessible only to piglets), which should be near to the udder (mostly at the side or in a corner). Recommendations for size of free farrowing pens range from 6.5 m^2 to 7.5 m^2 (Beilage, 2020). It is important to keep floors dry and warm to minimize injuries such as shoulder lesions, leg injuries and teat damage (Kilbride et al., 2009a,b).

Further research on housing systems for farrowing and lactating sows is needed to address the different requirements for piglets and sows in a limited space with respect to floor conditions and temperature. For lactating sows the upper critical temperature is approximately 21°C given the high risk of heat stress in sows due to increased metabolic rate, especially during birth and lactation (Ross et al., 2017). While normal breathing frequency is approximately 20 breaths/min, breathing frequency is increasing by an additional 30 breaths/min with every 2°C. This results in decreased feed intake followed by decreased milk production in lactating sows with a negative impact on piglet performance (Muns et al., 2016).

Sows prefer a room temperature of 18–20°C while the optimum temperature for new-born piglets is 32–34°C. A typical room temperature in farrowing units is 20–22°C, which is relatively warm for the sow but cold for piglets (Pedersen et al., 2013). During and after birth piglets are vulnerable to cold stress due to a lack of fatty tissue. Within 30 min, the body temperature can decrease by 5°C to a critical temperature of 33°C. Temperatures below 16°C result in rapid loss in body heat, which are potentially fatal. Readily accessible, heated creep areas for piglets are therefore indispensable (Villanueva-García et al., 2020). To ensure an air temperature of 32°C in the nest, the floor should be heated up to approximately 38–40°C with an even distribution of heat (Strauch, 2013). Heat lamps differ in wattage and light wavelength, which affects their use by piglets. Adequate heating can be assessed by the lying behaviour of piglets. The majority of piglets lie laterally with 40–50% touching each other (Lane, 2019). Recommendations for space of the nesting area range from 0.06 m^2 per piglet to 0.166 m^2 per piglet depending on lying recumbancy (www.freefarrowing.org, access 22.9.2021). The piglet nest should allowing relaxed lying by all piglets simultaneously (1.1 m^2 for 10 piglets at the end of lactation), with a roof, solid floor and ideally surrounded by three solid walls.

Suckling piglets should already have immediate access to water to avoid dehydration especially in hot weather conditions. Piglets drink about 50–65 mL/kg body weight. Larger water dispensers facilitate socialisation. Spillage

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from drinkers should not wet the floor. In well-designed farrowing pens piglets faeces and urine will be collected below the slatted area away from the warm and dry nesting area.

Group-farrowing pens allow early socialization of piglets who form social hierarchies rapidly with less aggression and injuries (D'Eath, 2004, 2005). However, group-farrowing pens are not widely used given problems such as cross-suckling of piglets and disturbing lactating sows. These disadvantages might not be outweighed by reduced later aggression between piglets (Pitts et al., 2000).

9 Specific housing requirements for nursery and fattening pigs

9.1 Nursery pigs

In nature, weaning is a gradual process that begins approximately 60–100 days after birth (Newberry and Wood-Gush, 1985). In accordance with Directive 2008/120/EC, no piglet should be weaned at less than 28 days of age, but they may be weaned up to 7 days earlier if they are moved into specialized housing separate from sows. In organic farms, piglets must be nursed for a minimum of 40 days. Stereotypic behaviour such as belly-nosing may indicate welfare issues during weaning and a slower growth rate (Straw and Bartlett, 2001). A comparison between pigs reared in confined or outdoor environments suggested belly-nosing and aggressive behaviour in outdoor piglets (Hötzel et al., 2004).

After weaning a transition period begins, in which gut maturation, odontiasis and behavioural changes take place; feed intake becomes biphasic with peaks in the morning and afternoon. The process of weaning is one of the most stressful events in the life of the pig. An additional challenge for the piglet is that, at the same time, an abrupt change of milk to solid feed occurs, during which passive immunity from sow milk declines while the piglet`s gut is still immature (Wei et al., 2021). It is therefore essential that transition of feeding should be as smooth as possible providing fresh and palatable creep feed from 7 days of age and feeding the same pre-starter in the first days after weaning. Higher intake of solid creep feed prior to weaning results in higher intake post-weaning although there are significant individual variations (Aherne et al., 1982; Muns and Magowan, 2018). For weaners bite-type nipple drinkers or pressure plate-operated bowl drinkers are used (1 drinker per 12 pigs), which should be installed above slats to avoid wet floors (Ocepek et al., 2018) (https://www.daf.qld.gov.au/business-priorities/agriculture/ animals/pigs/piggery-management/housing/basic-housing, accessed: 24.09.2021).

Weaners are often kept in specially-designed pens until approximately 10–12 weeks of age. Environmental parameters such as temperature and hygiene must be carefully controlled. Good pen design provides feeders and drinkers in the centre and lying areas next to walls to allow undisturbed resting. In some husbandry systems nursery pigs are kept in small groups, particularly where litters are kept together from weaning to slaughter. Leaving litters in the farrowing pen for some days after moving the sows reduces additional stress from moving and mixing with other animals whilst reducing pathogen transmission (Tobias et al., 2014). Leaving piglets from one litter together in a pen after moving to the nursery is preferable but not always economic (Faccin et al., 2020; Thomsson, 2008). 15m^2 is recommended as a minimum nursery pen size (Becker et al., 2020). The correct arrangement of feeding places, drinkers, enrichment and resting zones is critical for welfare. It is easier to monitor individuals in small groups of up to 20 pigs but pens are typically too small for an optimal layout.

Pen space can be used more efficiently when ≥5 litters of similar age are combined into larger groups. In large groups of more than 70 individuals, management is more challenging but an improved layout is easier to achieve given the larger space available (Becker et al., 2020). Growth performance of piglets can be impacted by large groups of 25–100 animals, especially if floor space is limited (Wolter et al., 2000, 2001). Group sizes of 20–50 pigs are considered a good compromise (Becker et al., 2020). High pig density is a significant factor in increasing the risk of tail biting (Bolhuis et al., 2006). Minimizing tail biting means adding more space which then allows more zoning and installation of toys or other enrichment materials (Moinard et al., 2003; Randolph et al., 1981). Nursery pens are often fully or partly slatted. A preferred maximum depth is 4 m with a width of 1.8 m which allows space for a shed width of 10 m (https://www.daf.qld.gov.au/business-priorities/agriculture/animals/pigs/piggery-management/housing/basic-housing, accessed: 23.9.2021). A common recommendation is, that the total depth of the pen should be at least double the width, because narrow and deep pens enable a separate area for defecation (EFSA), 2005). In pens with a partly slatted floor, one-third of the floor can be slatted with a slope of 1:25 and a clear demarcation of the solid floor. Fronts and gates of pens facing each other should be solid, while pigs of neighbouring pens should be able to see each other in the defecation areas (https://www.daf.qld.gov.au/business-priorities/agriculture/animals/pigs/piggery-management/housing/basic-housing, accessed: 23.9.2021). An overview of research in pen size recommendation and structuring of pens in different husbandry conditions can be found e.g. in recommendations by the European Food Safety Authority (EFSA), 2005).

9.2 Fattening pigs

In most farms pigs with an average weight of approximately 30 kg are moved to separate sections to be grown and finished for slaughter. Sorting pigs by weight when entering the fattening unit is also a common strategy to facilitate feeding management. Housing of fattening pigs has traditionally been characterized by limited space and a clean but stimulus-poor environment. This intensive rearing was justified on economical and health grounds (Millet et al., 2005). However, mixing of larger groups of fatteners in more confined conditions is associated with a higher incidence of stress and aggression (Meyer-Hamme et al., 2016). Alternative housing systems are characterized by more space and enrichment stimuli which can then result in improved weight gain and meat quality (Millet et al., 2005). Adding 25–50% more floor space for nearly-to-finishing pigs in the final 3 weeks of fattening was shown to significantly increase average daily weight gain and improve feed conversion rates, though more space can cause social tensions (DeDecker et al., 2005). Comparisons between outdoor and indoor systems reveal different issues. Slaughter data indicate that organic pigs reared in extensive systems had fewer respiratory problems, skin lesions and tail wounds compared to conventional pigs. On the other hand, joint lesions and white spot livers were more common with, in particular, a high level of exposure to endoparasites present in pasture conditions (Lindgren et al., 2014).

Minimal space allowance for fattening pigs up to 110 kg should be calculated using the formula: Area (m^2) = $0.047 \times BW^{0.67}$ in case, that heat stress can not be precluded, resulting in approximately 1.1 m2/pig. Those space requirements are significantly higher than those stated by the EU Council Directive 2001/88/CE (Table 4) and also higher than those calculated by other published formula: e.g. A (m^2) = $0.041 \times BW^{0.67}$ (Pastorelli et al., 2006). Based on the number of body lesions, Camp Montoro et al. (2021) found that, although compliant with EU legislation, space allowances for fattening pigs were detrimental to the welfare (Camp Montoro et al., 2021). The influence of stocking density can be seen in weight gain by fatteners. Pigs housed in a stocking density of 1.4 m^2/pig showed a 24 g higher average daily weight gain compared to those housed in a density of 1 m^2/pig (Corino et al., 2003). Other studies demonstrate the influence of stocking density on metabolism, intestinal morphology and immunity of growing pigs (Li et al., 2020).

Boar fattening is a new challenge in some European countries such as Germany, due to the ban on piglet castration without anaesthesia. It is common to leave boars intact, especially in Ireland, the UK and Portugal. Boars are more aggressive and show more mounting behaviours than castrated males. Risk factors for aggressive behaviour are too few eating places, restricted feeding, a low level of amino acids in the diet, insufficient water supply, disease, a suboptimal climate in the barn and fear of humans (Backus et al., 2016). Raising in sibling groups seems to reduce aggressive behaviour (Fredriksen et al., 2007). Maintaining pig health, stable social groups and sufficient physical resources are necessary to raise entire male pigs in accordance with good welfare standards (Borell et al., 2020).

The flooring system in fattening units is closely connected to handling of manure on a farm. Slatted floors are less labor intensive than solid flooring because feces fall through the slats into the slurry system, making it easier to keep floors clean. Most fattening systems are equipped with a fully slatted floor with no separation between lying and defecation/dunging areas. Gap width should be not more than 18 mm for fatteners. In general flooring and space affects the prevalence of disorders such as claw lesions, which can be assessed by abbatoir surveys (Alban et al., 2015). Claw lesions were found less often in finishing pigs kept on bedded floors compared to pigs on solid slatted floors. Pigs kept on slatted floors (partially and fully) show often specific heel, sole, white line and wall lesions (Mouttotou et al., 1999). This suggests that types of lesion are associated with different floor types (EFSA, 2005). Some authors have suggested that slat material (determining e.g. traction level, abrasiveness, hardness) is more important than the slat width for pig health and welfare.

10 Building-related biosecurity measures

The implementation of biosecurity measures in intensive pig production is easier than in extensive production which is more vulnerable to epidemic diseases such as African swine fever (Maes et al., 2019). External biosecurity measures are influenced by the location of the farm, the environment and economic aspects. Measures include fencing and hygiene locks to control access. A perimeter fence should demarcate the farm boundary and keep out wild animals such as wild boars. All visitors should stay at the perimeter. Containers for dead animals must be located outside the perimeter fence. Dead animals must be stored and disposed appropriately to avoid environmental contamination and infection of animals and humans. Birds are a potential vector of pathogens like Salmonella. This requires biosecurity measures to keep birds out by using bird-proof nets and closing doors and windows. Feed silos must be closed to avoid contamination by bird faeces. Where farmers do not have sufficient land to accommodate manure, it must be moved to other farms though this might lead to a spread of pathogens. A quarantine period for purchased gilts is mandatory. Contact between a quarantine unit and main farm must be prevented (Alarcón et al., 2021). A minimum safe distance to prevent transmission of diseases by air or vectors such as flies is 1000 m, although there are pathogens which can be transmitted over longer distances (e.g. foot and mouth disease virus) (Desrosiers, 2011).

Internal biosecurity measures must be implemented to prevent transmission of pathogens within the farm. Good hygiene practices include wearing personal protective equipment and preventing ill employees from entering the farm. Airborne transmission of pathogens between different units is a particular challenge. In herds located in pig-dense areas, airborne transmission between

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farms has been shown e.g. for PRRSV, *Mycoplasma hyopneumoniae,* swine influenza viruses and Aujeszky's disease virus (Maes et al., 2000; Desrosiers, 2011; Otake et al., 2010). Air filtration can help prevent infection (Alonso et al., 2013). Airborne transmission is less of an issue when negative air pressure caused by high ventilation rates in pens for fattening pigs (with a higher risk of infection) sucks in air from units with young animals with a lower risk. However, where a low number of animals is left in a fattening unit (e.g. because they are divided for sale by weight), air flow may go in the wrong direction, increasing the risk of infection of young pigs by pathogens shed from older pigs.

The movement of pigs through the farm is a critical factor in disease transmission. Diseased animals must be separated from healthy pigs. To efficiently remove an animal from a group for isolation or treatment, a small capture or hospital pen should be included in the pen design. There need to be hygiene steps implemented between different age groups to prevent passing disease on from one group to another. The AIAO system allows separation of age groups to minimize pathogen transmission between groups. An AIAO policy in the farrowing unit is e.g. particularly important to reduce transmission of *M. hyopneumoniae* (Nathues et al., 2013). Good hygiene practices such as routine cleaning and disinfection are essential in farrowing units, nursery and fattening units, including cleaning and disinfection of pens before a new group arrives. There is a temptation to hold back pigs of insufficient weight and integrate them into a younger batch but this should be avoided (Calderon Diaz et al., 2017). Batch farrowing of sows ideally with no more than 4–7 days between litters will increase the time available for cleaning floors, ceilings, walls, feeders and drinkers to reduce risk of pathogen spread between batches. A 5-week batch management system was found to achieve better disease control than a 4-week batch management system (Vangroenweghe et al., 2012).

Important cleaning steps are (https://www.thepigsite.com/articles/cleaning-and-disinfection; accessed: 15.07.21):

- Removal of movable pen equipment and separate cleaning in parallel with cleaning of walls and floors.
- Removal of dust by soaking the pen with water and detergent for approximately 24 h to dissolve proteins and fat.
- Pressure-cleaning with hot water using approximately 6900 kPa.
- Drying of all surfaces followed by disinfection of all surfaces
- The water dispensing system should be cleaned and disinfected and potential intruders such as insects or mice should be prevented from getting onto cleaned and disinfected surfaces.

Re-stocking 24 h after disinfection resulted in partially wet slats under natural ventilation, increasing soiling of floors which resulted in poor air quality and

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reduced growth rates (Murphy, 2011). More time is required (e.g. 2–3 days) to ensure pens are dry before they are restocked.

11 The importance of stockmanship

Stock people require a range of well-developed husbandry skills and knowledge to care for and manage farm animals. Negative behaviour like hitting and pushing pigs is associated with high fear levels in pigs, which is associated with reduced productivity in terms of reproductive performance of commercial sows (Hemsworth et al., 1994). Training to target technical skills and knowledge, as well as attitudes and behaviours, of stockpeople should be a primary component of human resource management practices on a farm.

Analogous to the 'Five Freedoms' three essential requirements of stockmanship are (Council, 2007):

- Knowledge of animal husbandry.
- Practical skills in animal husbandry.
- Personal qualities and attitudes.

Stock people need to understand the reasons for and have the training to implement appropriate practices to ensure the safety and welfare of pigs at all stages in their lifecycle, including skills in observing the animals in their care to identify potential health or welfare issues. In general, farms with large herds are able to offset the negative effects of herd size by a higher degree of awareness, better risk assessment processes, training, resources and procedures (Gardner et al., 2002; Laanen et al., 2013). The Report on Stockmanship and Farm Animal Welfare of the Farm Animal Welfare Council in the UK has highlighted issues in recruiting staff due to issues such as the negative image of livestock farming, long working hours and sometimes poor pay and conditions. In the long run there is a development towards automated monitoring, data analysis and process control (through precision livestock farming technologies) which will require a different type of stockperson (Benjamin and Yik, 2019).

12 Conclusion and future trends

To achieve sustainable livestock production, trade-offs between animal health, production efficiency, animal welfare standards and consumer protection must be avoided. There is a complex relationship between economic performance on the one hand and welfare on the other (Henningsen et al., 2018). Further complication comes from challenges such as antibiotic usage and environmental impact. However, a good farm manager can reconcile these requirements. Whilst there are many ways of measuring individual parameters, many are not practical on a large scale in practical farm settings. Selecting effective but workable criteria for the assessment of production systems in the face of conflicting goals will be the task.

Current and future challenges for pork production especially in Europe are:

i Implementation of new and more sustainable husbandry standards and stricter rules to meet environmental and animal welfare requirements. New regulations will increase costs for livestock production in the EU. Differences between EU countries with respect to national standards may lead to distortion of competition within the European Free Trade Association.

ii Developing new extensive husbandry systems. Whilst this may allow better expression of natural behaviours, the risk of (zoonotic) pathogens in the production chain will increase and external and internal biosecurity will be harder to manage. In addition, extensive systems make it hard to control emissions. The generally lower efficiency of extensive systems (higher feed conversion rates, lower average daily weight gain and higher animal losses) also raises issues of competitiveness as well as increased use of scarce land and feed resources.

iii Increased frequency of extreme weather events as a consequence of climate change. Periods of extreme heat in particular could lead to high production losses from heat stress, unless housing systems are suitably adapted.

iv Lower future availability of water. Water supply in Europe is a potential problem for almost half of its population, which is reflected by the Water Exploitation Index (how much water is consumed each year in relation to the total long-term freshwater resources in region). In the last 50 years renewable water resources per capita decreased by 24% in the European Union with about one third of the European countries being threatened by water shortage (https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-3/assessment-4, accessed: 14.07.21).

v Lower future availability of suitably trained and knowledgeable personnel. Farmers and stock people must now not only be experts in animal husbandry. Their knowledge must cover disease prevention, disease recognition, reproduction management, neonatal care, nutrition, and understanding behaviour. They must also manage and record a large quantity of data to fulfil legal requirements. The implementation of a hazard analysis and critical control point (HACCP) system would help to manage biosecurity, health and welfare as well as consumer protection. A HACCP-type standard has not been developed so far in swine production.

Digitalization of data streams, data bundling and management have great potential in meeting increasing requirements for higher standards and greater transparency within the pork production chain. Several systems are under development for data collection and digitalized data flow. Sensors for continuous measurement of various environmental variables are also available on the market and are used for automatic adjustment to ensure a stable micro-climate in barns.

Smart farming systems help to digitalize, connect and evaluate any data gathered in the farm environment for tracing, tracking and managing individual activities. Mobile applications (Apps) as software installed on electronic devices such as a smartphone, tablet, computer or other electronic devices facilitate data recording and are provided by various companies. In principle, all data can be bundled and controlled in one complex system. An integrated sow management system can, e.g. be based on scanning of electronic ear tags and communication with the smartphone, so that data relating to all activities, e.g. insemination, farrowing or weaning, are digitized. Such technological advances will support livestock farming by providing standardized measures to predict and better manage both productivity and animal welfare.

13 Where to look for further information

Modern swine husbandry is undergoing a major change: In addition to high animal-welfare standards, the focus is on improving production of safe and high-quality pork using climate- and resource-friendly production systems. In addition, the implementation of new digital technologies provide stockman with opportunities that have not yet been fully exploited.

Efforts to push forward developments to make food systems fair, healthy and environmentally-friendly are supported by the European Commission. Details on the farm-to-fork strategy can be read on the following site: https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en#documents (accessed: 28.04.2022).

While human and animal health are interconnected significantly influenced by the environment, the EU One Health Action Plan against AMR (antimicrobial resistance) also focus on the reduction of antimicrobials for farmed animals. Based on the knowledge that better animal welfare improves animal health, so that less medication is needed, the Commission will revise the animal welfare legislation. The actual development of EU Action on Antimicrobial Resistance can be read here:

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https://ec.europa.eu/health/antimicrobial-resistance/eu-action-antimicrobial-resistance_en (accessed: 28.04.2022).

There are several approaches to collect innovative projects by the EU. For the pig sector the thematic network 'EU Pig Innovation Group' is supporting innovative practices into pig production. The initiative belongs to the European activity within EIP-AGRI (agriculture and innovation). Search for projects is possible on the EIP-Agri site (https://ec.europa.eu/eip/agriculture/en/find-connect/projects/eu-pig-eu-pig-innovation-group-thematic-network, accessed: 28.04.2022). Good agricultural practice is also continuously followed by the Food and Agricultural Organisation of the United Nations, because pig production systems differ worldwide und should be developed towards sustainable production guaranteeing a high food safety (https://www.ciwf.org.uk/media/5492194/gap_pig_book_full.pdf, accessed: 28.04.2022). Several national information platforms for research projects but also for pig husbandry and pig welfare standards exist. One example is the Farm Animals-Pig Welfare site in UK (https://www.ciwf.org.uk/farm-animals/pigs/pig-welfare/ accessed: 28.04.2022).

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