Lighting in pig buildings: The principles

PORK

Contents

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Light and lighting

What is light?

Electromagnetic (EM) radiation is a type of radiant energy that moves through space in the form of a wave. The energy associated with EM radiation is contained within small packages called photons. The amount of energy contained within a photon is proportional to its wavelength, with the wavelength decreasing in size as the amount of energy it contains increases. For more information on photons, see the BBC summary.[1] The term 'light' is generally described as the region of the EM spectrum that is visible to the human eye, but for the purposes of this report we will use the term 'light' to refer to regions of the EM spectrum that can be perceived by pigs.

The natural light environment

In naturally lit environments, the main source of light is the sun, which produces photons with a wide range of wavelengths (Figure 1). Some wavelengths of light are filtered out by the atmosphere, so most of the photons reaching the Earth's surface have wavelengths measuring between 150 and 4,000 nanometres (nm).[2] Photons can be classified based on wavelength: ultraviolet C (UVC) = 100–280 nm, UVB = 280–315 nm, UVA = 315–400 nm, blue light = 400–500 nm, green = 500–600 nm, red = 600–700 nm, far-red = 700–800 nm and infrared 800–4,000 nm.

The amount of light present in the environment is highly variable across the globe and throughout the seasons. Three variables of natural light that are important for pigs are day length, the amount of light received and the wavelength (colour) of the light.

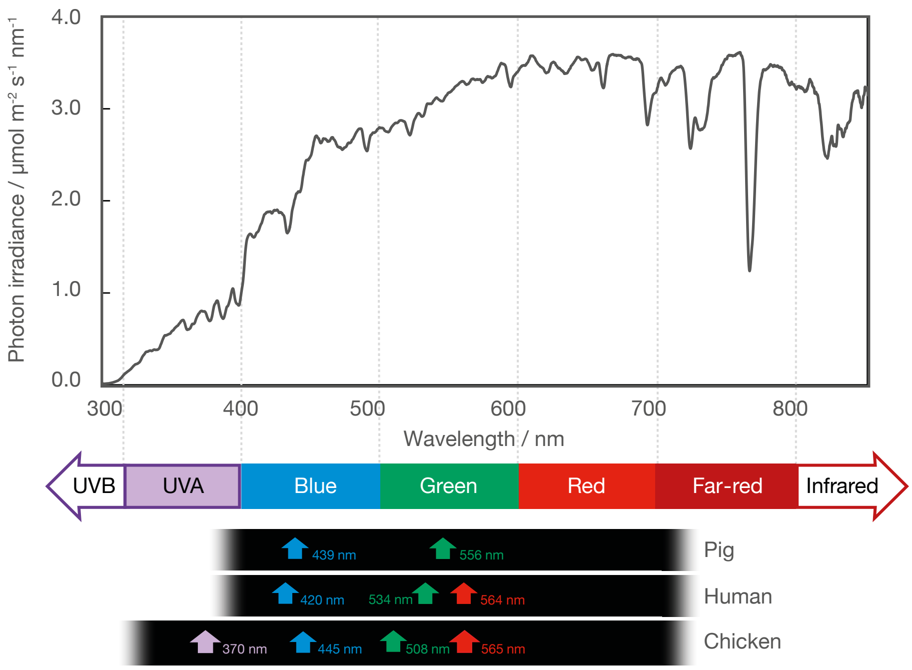


Figure 1. Spectral intensity of the sun measured at Stockbridge Technology Centre, Cawood, North Yorkshire on 28 April 2014. Y-axis units indicate the number of photons of each wavelength received from the sun. Coloured bar shows the wavelength ranges of different colours of light (from a human perspective). Black bars show approximate spectra range of vision of different species. Arrows and coloured numbers indicate the peak sensitivity of cone cells, which provide colour vision in each species

Day length

Close to the equator, the day length and amount of light received is relatively constant throughout the year (Figure 2) – weather patterns are the main factors affecting light availability. With increasing latitude (both northward and southward), both day length and light intensity become increasingly variable throughout the year. In North Yorkshire, day length varies from 7 hours and 6 minutes at the winter solstice to 15 hours and 6 minutes at the summer solstice – a variation of 9 hours and 42 minutes. Even within mainland Britain, day length can differ by up to 2 hours between John O'Groats and Penzance.

The photoperiod refers to the duration of time that an organism receives illumination, either from sunlight or through artificial lighting. For pigs that are raised outdoors, the photoperiod is equal to the day length. For animals raised indoors with no windows, the photoperiod is equal to the period during which artificial lights are turned on.

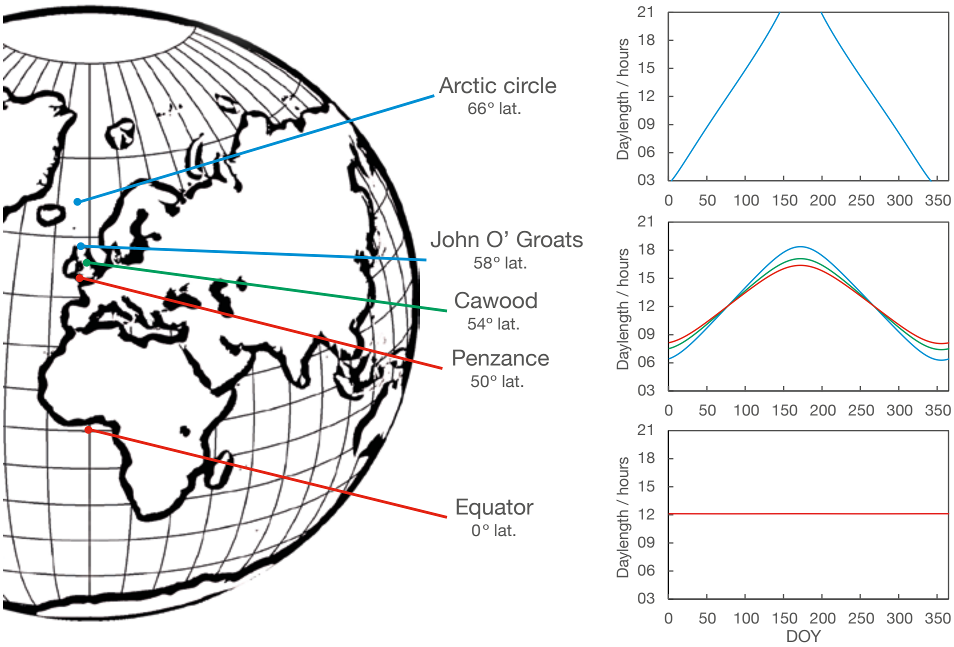


Figure 2. Effect of latitude on seasonal changes in day length (DOY = day of year from 1 January)

Amount of light

Measurements of intensity are taken 'on the spot' at a specific location and are not measured over time. It may be more appropriate to determine the total amount of light received over a certain period, usually 24 hours. To assess the total amount of light received at a location over time, multiple intensity measurements are made at equal intervals throughout the period of interest. These values are then integrated to calculate a daily light integral (DLI).

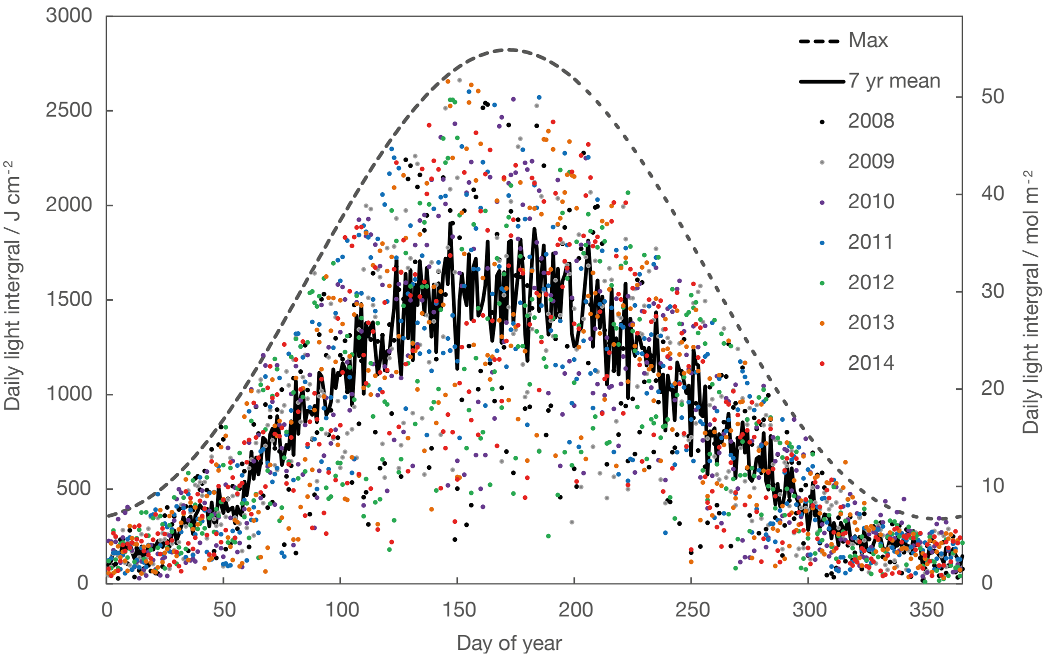


Figure 3. The measured daily light integral (DLI) over a 7-year period at Stockbridge Technology Centre. Individual points indicate the value measured on each day. The solid line indicates the mean value over the 7 years. The dashed line shows the calculated (theoretical) maximum DLI, assuming no cloud cover

The total amount of light available varies considerably through the seasons (Figure 3). At Stockbridge Technology Centre, the mean DLI for December 2017 was 3.6 mol d^{-1} (185 J cm^{-1} d^{-1}), while the mean value for July 2017 was nearly 10 times greater, at 30 mol d^{-1} (1,540 J cm^{-1} d^{-1}). Location within the environment can also have a significant influence on the light environment. In the northern hemisphere, south-facing slopes receive more light than northern-facing slopes and shade greatly reduces light intensity.

Colour of natural light

Throughout the day and seasons, there are subtle changes to the light spectrum. At low solar elevations, light must pass through a larger volume of the atmosphere before it reaches the Earth's surface than at higher solar elevations. As the atmosphere filters proportionally more of the shorter wavelengths of light, it causes changes in the spectrum; the atmosphere filters more UV than blue and more blue than green or red light.[2, 3] The amount of UVB radiation is particularly variable through the seasons and this also varies with altitude. The amount of UVB is much higher at high altitudes (mountain tops) because there is less atmosphere to filter out these harmful rays. The amount and spectral composition of the light that pigs would encounter in nature is also expected to change based on location within their foraging range. Below a forest canopy, the light intensity is greatly reduced and the light spectrum is significantly altered. Plants preferentially absorb red and blue light, which results in a greater proportion of green light in the spectrum below a forest canopy.

Visible light

Visible light refers to the wavelengths that can be detected and perceived by an eye. For humans, visible light has wavelengths between 360 nm and 720 nm. For other species, the wavelengths of light considered visible differ based on the structures and photoreceptors (Figure 1) present in the eye. Pigs are able to detect light with wavelengths between 380 nm and 760 nm. Birds, which have the ability to see UV, blue, green and red light, are likely to have an even wider spectral range.

The measurement of light

When a parameter is measured, it is important to report the value in units that are relevant to the final use of that data. For example, if the price of a building is quoted in £ per square metre, measuring the desired footprint of the building in feet and inches creates unnecessary work and inaccuracies can result when converting units. Conversions between different units can be made, but this should be avoided, where possible. Conversions between light units are complex because they depend on the spectrum of the light. Inaccurate conversions between units can lead to avoidable errors and can significantly affect results. In this section, we will briefly review the different units used to measure light.

Photometric light measurement – lumens and lux

Most artificial lighting systems have been developed with human vision in mind. Consequently, most technical data is reported in photometric terms that characterise light with reference to the human eye. Luminous flux (also called luminous power) is measured in lumens and defines the total output of a lamp (light emitted in all directions) that could be detected by the human eye. The energy efficiency of lamps is often reported as the 'luminous efficacy', which has units of lumens per watt of electrical input (lm/W). Lumens are useful for defining the total output and efficiency of lamps, but for most practical purposes, the amount of light reaching a surface (e.g., the light intensity received in the pig pen) is of greater relevance. This will account for the design and efficiency of the lamp reflectors, as well as the number and spacing of lamps installed.

Illuminance is a measure of the light incident on a surface. Illuminance is measured using units of lux, which are defined as the number of lumens per square metre (lux = lm m^{-2}). Instruments that measure lumens or lux are designed to have the same sensitivity to different regions of the electromagnetic spectrum as the human eye (Figure 4), which is most sensitive to green light (~550 nm).

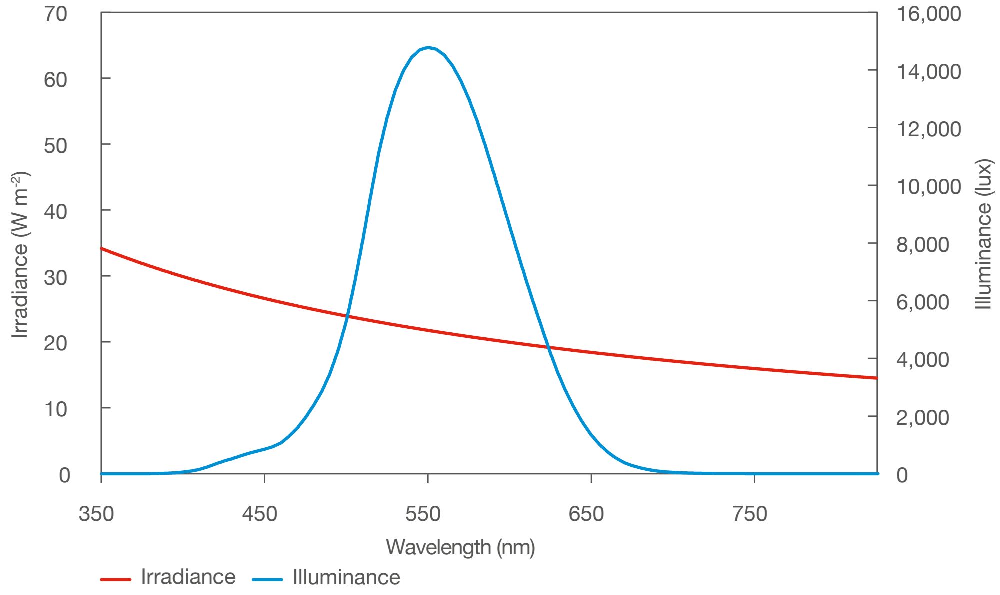


Figure 4. Differences in sensitivity to different regions of the light spectrum when measuring in different units. Values are calculated assuming the same number of photons are present at each wavelength

Radiometric light measurement – irradiance (W m^{-2})

While artificial light sources are often defined in photometric terms (lumens and lux), sunlight is more commonly measured in radiometric terms that measure the amount of energy contained within light. The radiometric equivalent of illuminance is irradiance (sometimes called radiant flux density). This provides a measure of how much light energy is incident on a surface and has units of watts per square metre (W m^{-2}) or watts per square centimetre (W cm^{-2}). While the spectral sensitivity of photometric sensors is defined by the spectral response of the eye, not all radiometric sensors measure over the same wavelength. Many commonly used sensors measure the full spectrum of sunlight (referred to as global radiation). While this provides useful data on natural light levels, these sensors are of limited use when comparing sunlight with light from an artificial source.

Photon counts – photon irradiance (μmol m^{-2} s^{-1})

A third method of light measurement is to count the number of photons reaching a surface – a value referred to here as photon irradiance. These measurements have units of micromoles per square metre per second (μmol m^{-2} s^{-1}). Note that the SI symbol for micro is 'μ' (10^{-6}), not 'm', which stands for milli (10^{-3}). Available sensors of this type have often been designed to measure light with wavelengths between 400 nm and 700 nm. They are often referred to as photosynthetically active radiation (PAR) or photosynthetic photon flux density (PPFD) sensors and have been used with crops. Given that the wavelength range is similar to that of both human and pig vision, these measurements may still be useful. This measurement also allows the amount of light being provided in each band (i.e., the amount of blue, green and red light) to be quantified.

Which units should I use to measure light for pigs?

All types of sensor are useful if the aim is to create a uniform light environment in pig production areas. Lux meters are generally of lower cost and so may, in the absence of better measurements, be most cost-effective. However, none of these measurement systems have been designed with pig vision in mind, so none provide the ideal solution. Each type of measurement has advantages and disadvantages.

Lux measurements estimate how the human eye detects light and are achieved by applying a biological weighting function with greatest sensitivity in the green region of the spectrum. It is thought that the pig eye has a greater sensitivity in the blue region of the spectrum than the human eye (see **Pig vision** for more detail), suggesting that measuring in lux may underestimate the light available for pigs.

Irradiance and photon irradiance measurements define physical characteristics of light and neither provides a pig-focused slant to the measured values. These sensors can be manufactured to sense light that is not visible to humans or pigs, so the spectral range should be checked before purchase. Sensors that measure wavelength between 400 nm and 700 nm are most appropriate.

For photon irradiance measurements, all regions of the spectrum are equally weighted (a red photon gives the same count as a blue photon), so can provide a useful estimate of the total light output of lamps. However, they are likely to overestimate the amount of red and blue light available for vision.

Additional research may help to define a light spectrum that is most appropriate for pig vision. It may then be possible to create a new measurement standard, provisionally referred to here as ‘pig-lux’. Utilising equipment that measures PPFD and ‘splits’ the resultant measurement between blue, green and red bands might provide an interim method of determining how much utilisable light reaches the pig eye.

How to take measurements of light

When taking measurements, all light sensors should be placed parallel to the floor – do not point the sensor at a light source because this will overestimate the light intensity. Ideally, measurements should be made at pig head height. Try to avoid shading the light sensor and be aware that lights may be located behind you. You should mount the sensor on a tripod and position yourself away from or below the height of the sensor so that the sensor can detect all down-welling light. Measurements should aim to account for the spatial variability in light intensity across the pig production area and the location of the lights. Measurements should be performed on a grid pattern across the area of interest, or alternatively, along transect lines running across the area of interest. Generally, the more measurements you take, the better the description of the light uniformity/variability. As a rough guide, to assess how the light intensity varies between two adjacent lamps, five measurements, at equal distance, should be made on a line between the two lamps, with the first and last measurements made directly below a lamp (Figure 5).

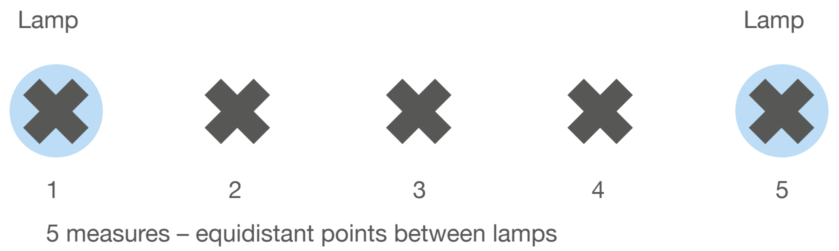


Figure 5. Demonstration of measurement location to be taken to assess the uniformity of light across a space

Overview of light technologies

Types of lighting technology are characterised by several variables, including spectral output, which can be compared to the spectral components of daylight. An overview of technology types and their output ranges follows (see Figure 6).

Incandescent and halogen bulbs

Incandescent bulbs function by heating a wire filament (made from tungsten) until it glows. The filament is enclosed in a glass bulb filled with inert gas to protect it from damage and oxidation. These lamps are the oldest and least energy-efficient type of electric light and, as regulators push for greater energy-use efficiency, are gradually being phased out in Europe. Halogen bulbs differ from incandescent bulbs in that they contain a halogen gas (iodine or bromine) that increases the life of the tungsten filament and can allow the bulb to operated at a higher temperature. One reason for the low energy-efficiency of these types of bulb is that much of the light they emit is beyond the (human) visible spectrum (i.e., they have low luminous efficacy).

Fluorescent tubes

Fluorescent tubes generate light by passing an electric current through a gas-filled glass tube containing mercury vapour. The electric current excites the mercury vapour, which then emits shortwave UV light. The UV light is absorbed by the phosphor coating on the inside of the glass tube. The phosphor coating then fluoresces to produce the required light. The colour of the light emitted can be altered by changing the mixture of phosphors contained within the lamps, or by adding filters to the glass. The luminous efficacy of fluorescent tubes can be greater than 100 lm/W.

High-intensity discharge lamps

Two types of high-intensity discharge (HID) lamps are commonly available: high-pressure sodium (HPS) and metal halide (MH) lamps. HID lamps function by passing an electrical arc between two tungsten electrodes, which are separated by a transparent tube filled with gas and metal salts. The heat generated by the arc evaporates the metal salts, which – at operating temperature – form a plasma that emits light. The spectral output of HID lamps is characteristic of the metal salts contained within the arc tube. HPS lamps contain mercury and sodium. During ignition, HPS lamps emit a pinkish glow. At this stage, only mercury vapour is emitting light, as evaporation of sodium only occurs at operating temperature. MH lamps contain mercury and metal halides (metal compounds containing iodine or bromine). HID lamps are more energy-efficient than fluorescent and tungsten lamps because a greater proportion of the light they emit is in the visible region of the spectrum.

Plasma and sulphur lamps

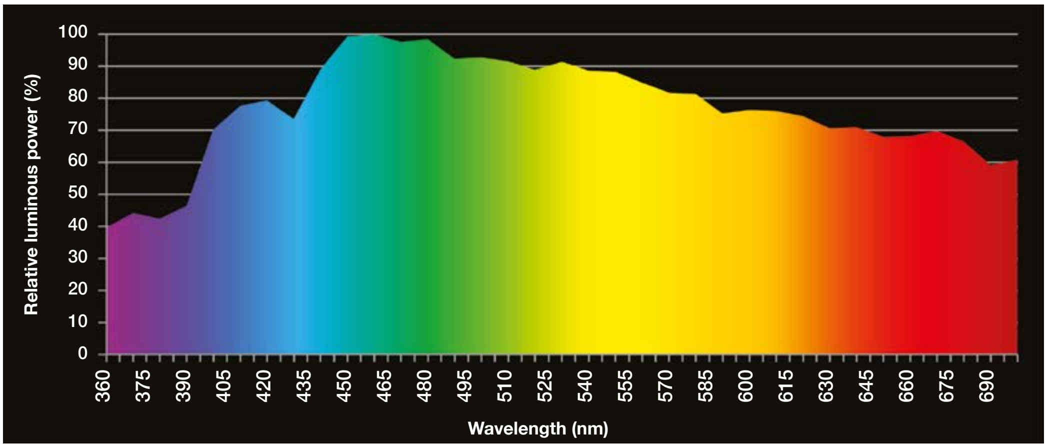
Plasma lamps are a type of gas-discharge lamp that generate light by heating a gas contained in a sealed glass vessel using high-frequency radio waves. In a sulphur lamp, the glass vessel contains sulphur, which is heated to form the plasma. These lamps contain no internal electrodes and are much smaller than the bulbs of HPS and MH lamps. The small bulbs mean that more efficient reflectors can be developed. As with other types of gas-discharge lamps, altering the gas mixture in the lamp can alter the spectrum, but once constructed, the spectrum is fixed.

LED technology

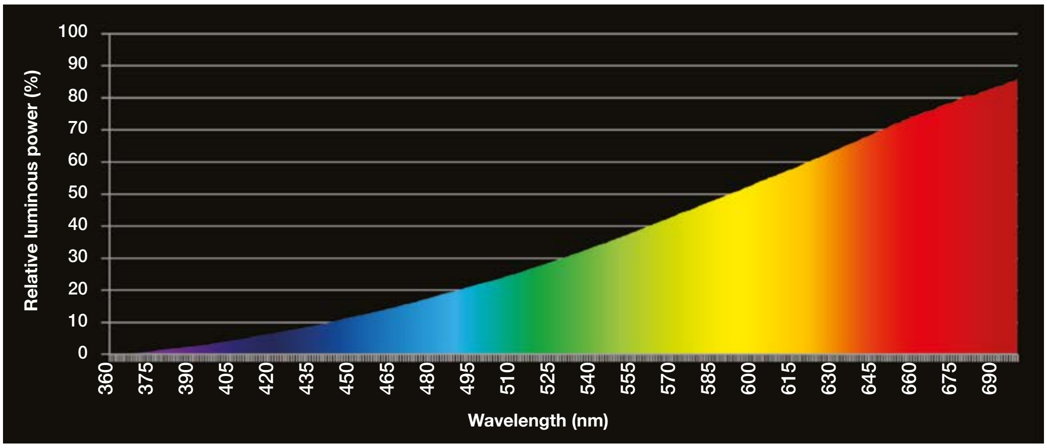
Unlike all other artificial lighting systems, light emitting diodes (LEDs) contain no glass or gaseous components: all the components are solid-state. LEDs are therefore less fragile than other types of lamp and they can be used in places where other lamps may become damaged and pose a health and safety risk. LEDs are constructed from two layers of semiconducting material in contact with one another. When an electrical current is passed through an LED, electrons move across the junction between the two materials. As they do so, the electrons fall to a lower energy level and release a photon in the process. The chemistry within the LED controls the size of the energy drops and, therefore, the wavelength of the photon emitted. LEDs are now available with almost any wavelength between ~240 nm and 4,000 nm, though their energy conversion efficiency differs with colour (red and blue LEDs are the most energy-efficient).

White light can be generated by one of two approaches: 1) combining red, blue and green LEDs, or 2) white LEDs. White LEDs are manufactured by adding a phosphor coating to blue LEDs. The phosphor absorbs some of the light emitted by the LED and re-emits the light with a longer wavelength (the same process that occurs at the wall of a fluorescent tube). The colour of white LEDs can be adjusted during manufacture by altering the mixture of phosphors. White LEDs are less efficient than standard LEDs for two main reasons. Firstly, the phosphor coating scatters the light emitted by the LED and this effectively traps some light within the LED. Secondly, as phosphors absorb blue photons and re-emit the energy as longer wavelength photons, some energy is converted to heat (this energy loss is referred to as a Stokes shift loss). Stokes shift losses can be up to 30%, but the most efficient phosphor (yttrium aluminium garnet, YAG) has a Stokes shift loss of just ~10% Thus, in 'white' LEDs that generate a significant amount of red light, there is a considerable loss compared with a red LED. One of the major advantages of LEDs is their high efficiency (light energy output/electrical energy input) over other lighting sources. While there are many things to be aware of when estimating the efficiency of LED lighting systems, it should be noted that LED technology is advancing at a considerable pace. Each decade, the efficiency of LEDs has increased approximately 20-fold, while the cost per lumen emitted has fallen by a factor of 10 (Haitz's law).

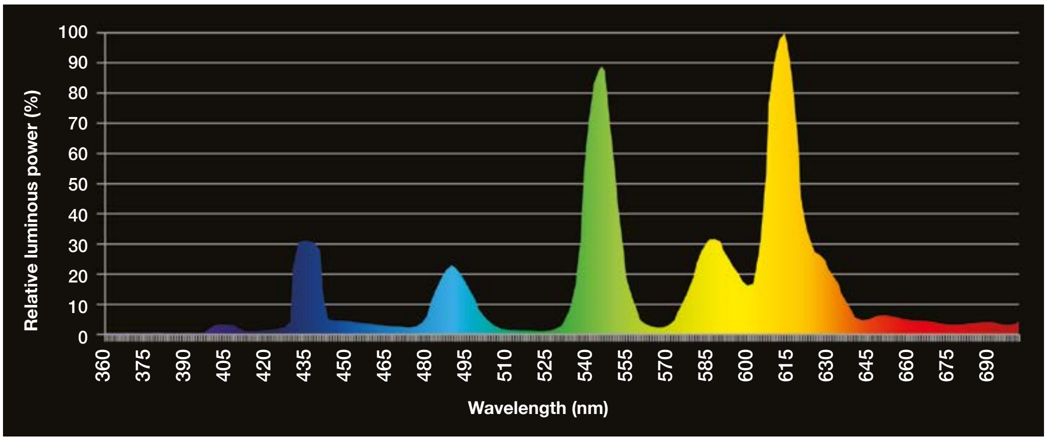
The advantages of LED technology can be seen in the design of the lamps they are used to construct. Unlike other types of lighting systems, the light emitted from an LED is directional; optical design of LED lamps therefore differs from other lamp designs. The need for reflectors is reduced because no light is emitted from the back of the LED, although reflectors can still be useful for shaping the light beam. Instead of reflectors, many LED-based systems implement lenses to direct the light beam to the desired location. Good optics can reduce the amount of stray light and ensure that the light is directed to where it is wanted. The emission spectrum of an LED, like other types of lighting technology, cannot be changed. However, the overall spectrum of an LED lamp can be modified for different applications by changing the number and colours of LEDs installed in the unit. Lamps can also be designed to alter the intensity of each colour of light, so the emission spectrum can be modified at will.



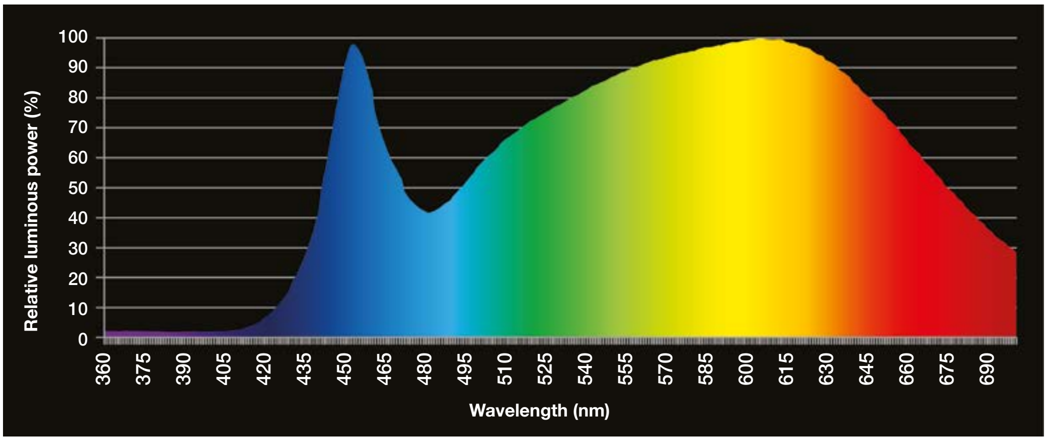
A) Spectral components of daylight



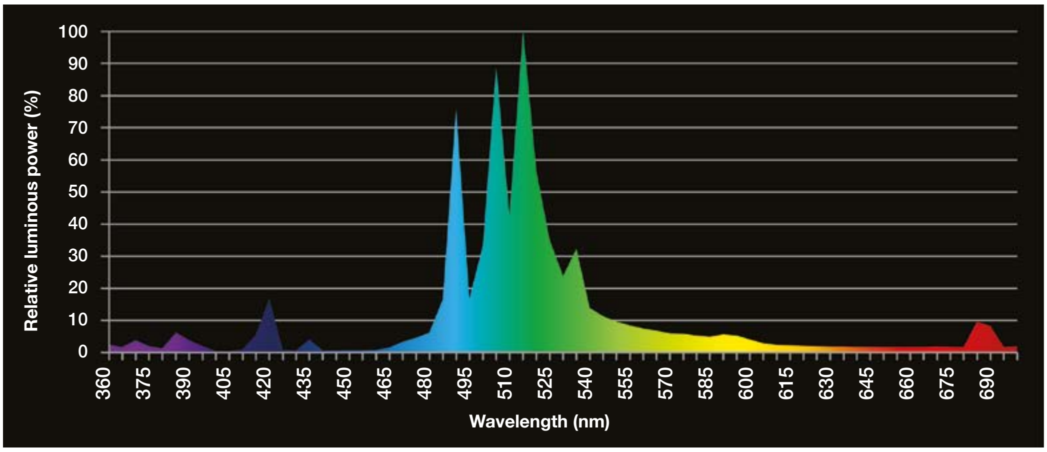
B) Incandescent lamp



C) Warm white fluorescent lamp



D) High-pressure sodium lamp



E) LED mid-colour-range lamp

Figure 6. Spectral outputs of a variety of lighting sources. A) Spectral components of daylight; B) Incandescent lamp; C) Warm white fluorescent lamp; D) High-pressure sodium lamp; E) LED mid-colour-range lamp [4]

Legal lighting requirements for pigs

EU and UK legislation

The Council of the European Union[5] states the following minimum lighting standards within Council Directive 2008/120/EC:

> **Annex 1. Chapter 1. General conditions. Standard 2:** Pigs must be kept in light with an intensity of at least 40 lux for a minimum period of 8 hours per day.

The World Organisation for Animal Health (OIE)[6] reports:

> **Article 7.X.18:** The ad hoc Group reinstated the justification for not accepting the request of a Member Country to mention the limit of 40 lux as a light intensity recommended to avoid increased aggression. In its previous report of August 2017, the ad hoc Group, following a recommendation of another Member Country, had removed the reference to this limit. However, the ad hoc Group emphasised the requirements for a suitable photoperiod and provision of suitable lighting levels for caretakers to properly inspect pens and animals. The ad hoc Group further noted that this was justified because of a general shortage of studies looking at lighting levels, not because any contradictory results have been found regarding the 40-lux recommendation.

The Welfare of Farmed Animals (England) Regulations (Amendment) 2010[7] outline the general conditions, including lighting, under which farmed animals must be kept in England:

> **Schedule 1. Inspection. Line 3:** Where animals are kept in a building, adequate lighting (whether fixed or portable) must be available to enable them to be thoroughly inspected at any time.
>
> **Schedule 1. Buildings and accommodation. Lines 14–16:** Animals kept in buildings must not be kept in permanent darkness. Where the natural light available in a building is insufficient to meet the physiological or ethological needs of any animals being kept in it, appropriate artificial lighting must be provided. Animals kept in buildings must not be kept without an appropriate period of rest from artificial lighting.
>
> **Schedule 8. Artificially lit buildings. Line 7:** Where pigs are kept in an artificially lit building, lighting with an intensity of at least 40 lux must be provided for a minimum period of 8 hours per day.

The Code of Recommendations for the Welfare of Livestock: Pigs[8] advises on compliance to the above regulations and related laws, including the Animal Welfare Act 2006, which further states:

> **Schedule 1. Lighting and noise. Line 59:** You should have enough fixed or portable lighting available at any time if you need to inspect any animals, for example, during farrowing.

Scotland/Wales/Northern Ireland:

The Defra codes reflect the responsibilities of the devolved governments, which outline individual requirements as stated below.

The Welfare of Farmed Animals (Scotland) Regulations 2010 (S.S.I. 2010 No. 388)[9] state:

Schedule 1. Paragraphs 3: Where animals are kept in a building, adequate lighting (whether fixed or portable) must be available to enable them to be adequately inspected at any time. Animals kept in buildings must not be kept without an appropriate period of rest from artificial lighting.

Schedule 6. Part 2. Paragraphs 7/18: Where pigs are kept in an artificially lit building then lighting with an intensity of at least 40 lux must be provided for a minimum period of 8 hours per day.

The Welfare of Farmed Animals (Wales) Regulations 2007[10] also outline:

Schedule 8. Regulation 5. Paragraph 7: Where pigs are kept in an artificially lit building, lighting with an intensity of at least 40 lux must be provided for a minimum period of 8 hours per day.

The Welfare of Farmed Animals (Northern Ireland) Regulations 2012[11] repeat:

Schedule 1. Paragraph 16: Animals kept in buildings shall not be kept without an appropriate period of rest from artificial lighting.

Schedule 8. Paragraph 7: Where pigs are kept in an artificially lit building, then lighting with an intensity of at least 40 lux shall be provided for a minimum period of 8 hours per day.

Outdoor pigs

There are no requirements for artificial lighting for outdoor pigs. The Welfare of Farmed Animals (England) Regulations[7] and the Defra Code of Recommendations[8] state that adequate shelter must be provided to protect the animals from extreme weather conditions and, specifically, that adequate shelter must be provided to protect the animals from the sun in summer. Although this provision is to decrease the risk of sunburn or heatstroke in the animals, it may also allow them to avoid bright illuminances if they so choose.

Tail biting

Lighting should be referenced with respect to tail biting;[22] the Scientific Veterinary Committee (SVC) report mentions that, despite little experimental evidence, excessive light levels are a possible cause of tail biting outbreaks. Temperature is known to have a major influence on tail biting and indeed, Van Putten[12] found a decrease in tail biting when pigs were housed in a warm environment under low lighting. Van Putten[13] also found an association between high illuminance fluorescent lighting and tail biting, but this may also reflect the probability that housing types expected to cause tail biting (fully slatted, artificially ventilated housing) also used fluorescent lighting.[14, 15] The type of lighting likely to affect pigs sufficiently to contribute to tail biting would be continuous, high-intensity light, with continuous lighting shown to generate more active and more agonistic pigs.[16] A study co-commissioned by AHDB[17] on tail biting risk assessments did not include lighting as an individual high-risk factor, but noted the effect of lighting when included with other factors such as high humidity.

Future legislation

Current regulations are derived from EU legislation and are based on the report of the EU's Scientific Veterinary Committee.[18] European Union regulations were based on this report to produce Council Directive 2008/120/EC.[5] When the UK leaves the EU, all current EU legislation will become UK law. At some point in the future, these regulations may be revised, but new legislation is unlikely to weaken these regulations. Hopefully, any future revisions will be based on sound scientific data, if available. Farmers continuing to trade internationally may have to account for different or changing regulations in the countries of export (see **International regulations**).

The 2018 Defra consultation draft[19] for a proposed 'new statutory code of practice for the welfare of pigs, England' states, in paragraph 96, that:

> Where pigs are only provided with artificial light, a normal 24-hour rhythm must be followed with a minimum of 8 hours darkness. Owners/keepers should routinely check and keep a record of light levels in pens at all stages of rearing, including farrowing accommodation.

While this code does not yet apply to the keeping of pigs and it is unclear as to when or if these specific conditions will be included, it is important to consider any potential legislation in trial work or when installing equipment in new or existing pig units.

Additional requirements for welfare schemes

Farmers may opt (or be required by a customer) to join a national welfare assurance scheme for indoor-housed pigs, or a farm assurance scheme associated with a supermarket. These schemes require adherence to additional regulations, some of which aim to provide welfare standards above the legal minimum. Some, but not all, of these schemes have additional guidance for pig lighting.

The RSPCA welfare standards for pigs[20] include the requirements that:

In each period of 24 hours, housed pigs must have access to an area that provides:

- A period of at least 8 hours of continuous light, with a minimum intensity of 50 lux, except that this may be lowered to correspond with the duration of the natural daylight period at the time if this is shorter
- A period of continuous darkness of at least 6 hours, except that this may be lowered to correspond with the duration of the natural darkness period at the time if this is shorter

Records of lighting regimes must be kept.

They also note that:

- Fifty lux is bright enough to allow a person of normal eyesight to read standard newsprint without difficulty
- Recent research has indicated some benefits of providing pigs with a longer light period, where artificial light is used and the switching on/off of artificial light in a stepped or gradual process
- The RSPCA is looking into the benefits of providing natural light

Red Tractor Assurance Pigs Standards[21] state that:

- Housing must be lit to allow normal behaviour repertoire, rest and effective inspection of livestock
- Access to either natural or artificial light – period of darkness each day, unless heat lamps are in use with suckling sows and piglets

Note: Heat lamps, or infrared lamps, produce small amounts of light as well as heat. If heat lamps are used to support the health and growth of suckling piglets, the light given off is regarded as negligible for the short duration that the lamps are in use.

International regulations

Other EU countries stipulate lighting beyond current EU legislation. Austria requires pigs to have access to daylight if there is no outdoor access; Belgium and Sweden both require that natural daylight is provided; Germany requires that pigs are housed under 80 lux for at least 8 hours per day and that they have access to daylight.[22] Access to daylight is required 'through wall or roof' in Belgium, Germany and Austria; Sweden requires the provision of daylight via windows.

Australia: The Victorian Standards and Guidelines[23] suggest natural or artificial light of at least 20 lux be made available at pig level, in all buildings, for a minimum of 9 hours daily.

New Zealand: The National Animal Welfare Advisory Committee[24] outlines minimum standards, which must provide pigs with natural or artificial light (of at least 20 lux at pig level) at an appropriate intensity for a minimum of 9 hours each day.

Canada: The National Farm Animal Care Council (NFACC)[25] requires that:

- Sufficient lighting is available to permit thorough inspection of pigs and facilities at any time (and for normal husbandry practices)
- A minimum of 50 lux of lighting (described as bright enough to allow a person of normal sight to read standard newspaper print) is provided for a minimum of 8 hours per day
- Pigs have access to a darkened area (i.e., ~5 lux or less, except for heat devices in farrowing areas and the first 48 hours for newly weaned pigs) for at least six consecutive hours per day
- The NFACC also recommends to:
- Match the intensity/location of the lighting to the purpose of the area that the lighting affects
- Provide lighting in a range of 150–250 lux in handling facilities
- Leave lights on for piglets during the first 24 hours post-weaning to facilitate the initiation of feeding

United States: The National Pork Board (NPB)[26] advises that lighting should give enough illumination to allow good husbandry, adequate inspection of pigs, maintenance of wellbeing and safe working. The NPB states no particular daily photoperiod is necessary for growing pigs and references recommended levels: 20 foot-candles for special inspection areas; 15 foot-candles for breeding, gestation and farrowing areas; 10 foot-candles for nurseries; and 5 foot-candles for growing and finishing areas. For reference, 1 foot-candle is equal to 10.76 lux.

South Africa: The Real Pig Handbook[27] recommends at least 12 hours of light per day (at a minimum 100 lux) and if normal daylight is insufficient, artificial lighting should follow the circadian rhythm. Windows must be arranged for even light distribution, with window areas in new buildings of a minimum of 3% of the floor space (in exceptional cases, 1.5%).

Opportunities for research to improve future guidance

Although legislation requires pigs to be provided with a period of darkness, there is no scientific evidence to suggest at what intensity pigs consider it to be dark and no definition of darkness has been provided. This leaves the legislation open to interpretation. The spectral requirements of lighting for pig buildings have not been specified (which will affect pigs' perception of illuminance).

How do pigs sense different light qualities? (Pig photobiology)

Ecology of pigs and natural light environments

Understanding the ecology of pigs can provide information on the environmental conditions their eyes have evolved to cope with. Most non-domesticated pig species occupy habitats with good foliage cover and show crepuscular behaviour (ie., they are most active during dawn and dusk).[28, 29, 30] Human activities such as hunting, high or low temperatures and changes in food availability can induce nocturnal or diurnal behaviour patterns. Similarly, domestic pigs show a more crepuscular activity pattern[31] than a conventionally diurnal one.

Based on ecology, pigs are equipped with a visual system that can cope with a comparatively wide range of light intensities and this may make their visual system more adaptable than that of a species evolved specifically for nocturnal or diurnal activity. Wild boar and the domestic pig demonstrate use of vision in a wide variety of biologically relevant settings, e.g. communication with conspecifics, reaction to aversive stimuli and preference for different illuminances.

The structures of the porcine eye: implications for vision

The physical properties and structures of the eye can provide evidence for the visual abilities and limitations of a species. In relation to natural light environments, domestic pig vision appears to be adapted to intermediate light environments, with features appropriate for both diurnal and nocturnal life.

Visual acuity

Acuity is the upper limiting point of spatial vision – it allows the perception of fine detail, but not the perception of shapes or forms in the real visual environment. Acuity is a useful measure of the visual ability of the eye/animal to distinguish between visual cues that could play a role in its behaviour. Good visual acuity enables familiarity and ease of movement around an animal's environment,[32] discrimination or recognition of other animals[33] or stockpersons[34] and location of food and water.[35] Acuity calculations for the pig eye suggest it has a resolution approximately one-sixth of that of the human eye, although behavioural experiments suggest it is lower. Compared with wild boar, the domestic pig has a lower photoreceptor and ganglion cell density,[36] as well as a smaller visual cortex.[37] This suggests that domestication has reduced its ability to detect and process visual information (or that factors associated with vision have not been selected in genetic improvement programmes).

While pigs' acuity may be inferior to humans', their visual gearing towards different components of visual information should not be underrated. Pigs may be more attuned to detect or discriminate other features of visual stimuli than spatial detail (movement, shape, edge detection). The importance of appropriate lighting for visual tasks should not be underestimated. Evidence to support this has been provided by a study[38] on the effects of light intensity and object size on the pig's ability to distinguish visual cues. The study showed that reduced illumination increased the rate of incorrect choice within the test conditions. However, the size of the cue had a larger effect than illumination levels on the pig's ability to choose the correct cue.

Colour vision in pigs

Spectral sensitivity is the ability to discriminate between different wavelengths of light, i.e,. to see in colour. For colour vision, an animal must be able to simultaneously process information from at least two types of photoreceptor cells.[39] The perception of different wavelengths depends on the combined sensitivity of cone cells found in the eye and the neural transfer of this information.

Electrophysiology and retina

Electrophysiological studies of pigs' cone cells (Figure 1) show two classes of receptor, with peak sensitivities to wavelengths of 439 nm (blue) and 556 nm (green).[40] In contrast, humans and some other primates have three types, enabling additional contrasts in the green/red region of the spectrum. It is unlikely that pigs can visually detect UV light.[41, 42]

In pigs, the blue and green cone cells are found throughout the retina and almost all regions contain >10% blue cone cells.[43] Pigs have a considerably more dense distribution of blue cone cells than humans, suggesting they are more sensitive to blue light.

Behavioural assessment of colour vision

While electrophysiology experiments demonstrate the colours that different species can physiologically detect, behavioural experiments are required to show that the animal can perceive and respond to different colours.

Initial attempts to prove colour vision in animals were based on training animals to discriminate between coloured objects. The major limitation of this approach is that the animal may be able to distinguish between objects based on other cues (especially brightness or scents of dyes). Attempts to match the brightness of different coloured cues are automatically limited by using human vision or anthropocentric devices (lux meters) to match brightness, which are inherently different from the spectral sensitivity of the animal being tested.[41, 44, 45]

An alternative method is to measure the animal's discriminative ability over a variety of cue brightnesses. The results of coloured cue discrimination tests in pigs indicate that the perception of blue cues is different from the perception of grey, green or red cues. Pigs struggle to discriminate between the latter three cues.[46, 47]

The spectral sensitivity of the animal can also be investigated using brightness perception, typically using illuminated coloured cues. The animal is presented with lit and unlit stimuli and is trained to distinguish between them using brightness alone, with brightness of the lit source being incrementally varied until a threshold of perception is reached.

Klopfer[42] showed that pigs are able to detect wavelengths between 420 nm and 760 nm when these were presented separately, but could not detect 820 nm at the intensity provided. The pigs showed different levels of sensitivity to the wavelengths presented, with a peak in sensitivity at 550–595 nm and a smaller peak at 465 nm.

Taylor[41] found that pigs are able to detect wavelengths between 380 nm and 694 nm. Most pigs showed peak sensitivity in the blue range (either to 415 nm or 450 nm) and reduced sensitivity in the UVA (below 380 nm) and red (above 577 nm) ends of the spectrum. Human data (using the same equipment) showed a peak at 450 nm. Pigs showed similar sensitivity to blue wavelengths, but reduced sensitivity to red wavelengths compared with humans – all humans (8/8) could detect 694 nm, but only 3/6 pigs could detect this.

Behavioural and electrophysiological data are highly correlated, showing the validity of both methods in determining complementary aspects of spectral sensitivity;[48] the two methods supplement each other to produce the fullest picture of colour vision in an animal.

Perception of lamp flicker

An additional characteristic of artificial lighting, which may influence its appropriateness for use with animals, is the flicker (100 Hz or 120 Hz) inherent in magnetic ballast fluorescent sources. Fewer studies have been done on this aspect of lighting, especially regarding mammals, although it has been studied in poultry[50] and starlings.[51] Under visible frequencies of flicker, humans report a variety of unpleasant effects that increase with the visibility of the flicker, e.g. visual fatigue,[52] epileptic fits,[53] headaches and migraine.[54] Current best estimates suggest that pigs should be unable to detect the flicker of correctly functioning fluorescent tubes.[55] However, pigs may be able to detect the 50 Hz or 60 Hz flicker of fluorescent light sources as they begin to fail, so light sources with flicker that is visible to humans should be removed from pig housing. This effect may also be relevant when light enters the pigs' environment through a rotating fan.

Light and ocular pathologies (eye health)

Suboptimal lighting can affect the development and function of the eye. In poultry, buphthalmia (enlarged eyes) can occur under continuous darkness, continuous high illuminance and under photoperiod systems with low illuminance.[56] However, buphthalmia has not been recorded in pigs and it is suggested that the wide aperture for humour outflow means the pig eye is incapable of becoming buphthalmic.[57, 58]

Continuous high illuminance can affect the mammalian eye; albino rats show rapid reduction in visual ability when outer segments of the photoreceptors are destroyed[59] – even continuously low light levels induce retinal degeneration.[60] Adult minipigs kept under continuous 2,500 lux[61] showed outer nuclear layer thinning in the retina and reduced and slow pupillary reflex to light (compared with controls kept at 1,000 lux, 12L:12D light:dark). Although these conditions have not been recreated for domestic pig breeds, the development of the eye of minipigs is thought to be the same.

Few ophthalmological problems are found in the commercial pig,[56] although miniature breeds have high incidences of membrane remnants, etc., which may be related to inadequate eye development.[62] Vitamin A deficiency also affects eye development in piglets.[63] The red/infrared and UV sources used by Wheelhouse and Hacker[64] did not damage the eyes of the pigs they housed.

Ultraviolet – vitamin D and sunburn

UV is necessary to synthesise vitamin D3 in humans and pigs. Cooper et al.[65] estimated that 1–2 minutes of exposure to natural UV levels per day is sufficient for pigs to produce adequate levels of the vitamin. However, standard pig diets contain vitamin D2 and Bethke et al.[66] showed that vitamins D2 and D3 are equally effective in supplying the vitamin D needs of swine. Lauridsen et al.[67] found a decrease in the number of stillborn piglets when using 1,400 IU vitamin D or higher. Gilts showed improved bone strength and bone ash content when more than 800 IU vitamin D3 was provided.

Additional shelter and wallows for outdoor animals reduces risk of sunburn and exposure to UV radiation. Indoor animals should also be able to avoid direct sunlight (some windows exclude most UV light). As vitamin D requirements can be met via the diet, artificial lighting systems do not need to include UV light.

Circadian rhythms

All animals, plants, fungi and bacteria possess a circadian rhythm that oscillates with a periodicity of approximately 24 hours. These rhythms help organisms to adjust their metabolism and behaviours to match day/night cycles. Circadian rhythms run endogenously and independently of external stimuli, but can be entrained by external signals, such as light and heat. Entrainment ensures that the clock stays in phase with the local light/dark cycle. Circadian rhythms in pigs can be observed by changes in body temperature, activity and the levels of some hormones, such as cortisol.[68]

In mammals, melanopsin is the blue-light photoreceptor (with a peak sensitivity at 480 nm) that functions to entrain the circadian clock. Melanopsin is found in light-sensitive ganglion cells in the retina, but functions independently of the vision system.[69] These light-sensitive ganglion cells send a signal to the pineal gland, via several neurological structures, to regulate the gland's production of melatonin. Melatonin is produced in darkness (blue light inhibits production) and is important for regulating sleep/wake cycles.[70] Despite earlier contradictory findings, an overnight rise in melatonin has been found in pigs,[71, 72] which is equivalent to that of the European wild boar.[71] Tast et al.[72] found that melatonin cycles were measurable in pigs when exposed to illuminances of 40 lux during the photoperiod.

When travelling between time zones, humans (and presumably other organisms) experience jet lag during the period required for the body clock to be entrained to the new 'phase-shifted' light/dark cycle. Understanding entrainment to a new light/dark cycle in pigs is important when examining responses to changes in day length, or the effect of day length alone. The influence of pre-test conditions is a key issue that is often overlooked; this affects perceived changes in photoperiod and illuminance, which in turn affects pig performance and physiology under test conditions.[73] For example, an experiment performed under a 12-hour photoperiod may provide different results if the pre-test conditions were to change. Pigs taken from an 8L pre-treatment would perceive a longer day length, but pigs taken from a 16L pre-treatment would perceive a shorter day. Pre-test conditions are rarely described, but this is especially critical if animals have come from outdoor or naturally lit environments with varying photoperiods. In 2001, Tast et al.[71] stated that 1 week is sufficient to entrain pigs to a new circadian rhythm but, by 2005,[74] commented that 6 weeks may be insufficient for pigs to acclimatise, so an acclimatisation period may also play a major role in the interpretation of results. In view of some of the seasonal effects noted in wild boar, knowing the birth month of animals involved in seasonal studies would also be informative.

Health implications

Disruption of the circadian rhythm has been linked with a variety of health consequences in humans and animals, including premature death, mood disorders, reproductive problems and cancer.[75] Melatonin is implicated in the regulation of hormone production by the pituitary gland,[76] has antioxidant properties[77] and interacts with the immune system.[78] In pigs, supplementary melatonin can reduce the existing stomach ulcers and ulcer prevalence.[79, 80] This raises the possibility that using a 'correct' dark period, i.e., to maintain a sufficient level and duration of darkness for optimal melatonin production, could benefit health and strengthens the argument that a dark period is as important as a light period.

Seasonality and melatonin

Seasonality is also controlled by changes in melatonin production that occur in response to changes in photoperiod.[81] There are two predominant theories on how melatonin mediates seasonal information in the mammalian endocrine system:

1. The subject's endocrine system reacts to an 'absolute' concentration of melatonin circulating in either the blood or cerebrospinal fluid (CSF – although the involvement of the CSF has been largely discounted in the literature).
2. The subject's endocrine system responds to increases or decreases in melatonin concentration (again in blood or CSF) over time.

The latter theory appears to be more generally accepted and is supported by various studies demonstrating the widely variable concentrations of melatonin between individuals in populations kept under identical conditions.[82] In some animals, this variation in concentration has been linked to variations in pineal gland weights – the pineal gland being the main site of production of melatonin.[83]

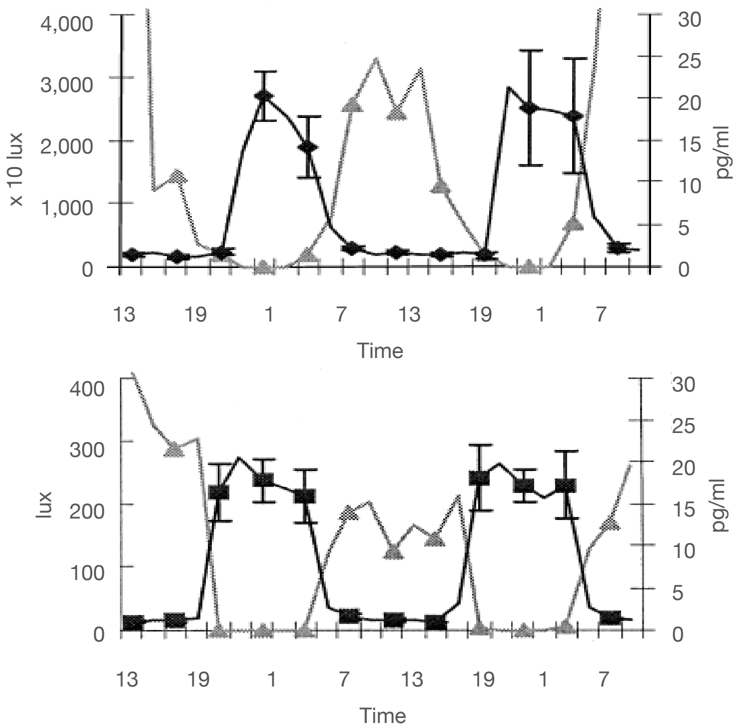
It is appropriate to consider that seasonal changes in animals occur in response to decreasing or increasing photoperiods, as opposed to long or short days alone driving these mechanisms.[84] Some of the research described below demonstrates a clear response to a 'fixed' (either long or short) photoperiod. It is important to understand the biology that underpins the response, i.e. how the changing seasons affect the endocrine system.

Seasonality in modern pigs

European wild boar maintain an obvious seasonality: rutting in October/November, gestation from December with peak farrowing in March–April and an anoestrous period in the sow in June–July until late autumn in mature animals. The pattern in primiparous sows (sows in their first reproductive season) is subtly different, with gestation through April–July and piglets born in July–August.[85] This is thought to be because gilts (born March–April) need over a year to mature. Experiments with domestic pigs frequently use gilts to compare light treatments because gilts are known to be more seasonally responsive than sows. However, if domestic pigs are still governed by this difference in breeding period because of age, while sows would be expected to adhere to a short-day breeding pattern, gilts may similarly come into oestrus under decreasing day lengths if mature enough to breed. If too young to breed during autumn, they may show delayed puberty, with oestrus triggered by increasing day lengths to coincide with the next spring.

Different degrees of seasonality are reported from different countries, ranging from distinct short-day breeders[86] (conventionally in countries from 50–60° North and 30–40° South[87]), to no seasonal changes.[88] The variation in seasonality may reflect the origins of the domestic pig, with input from progenitor species whose seasonality was determined by the climate in which they evolved, as well as the current climate experienced by farmed animals. As with poultry,[89] commercial pressures have encouraged selection for photo-refractoriness (when reproduction is no longer regulated by season/day length) in pigs to reduce fluctuation in productivity. Most commercial pigs are no longer strictly seasonal and most breeds are expected to have more than two litters per year, so photoperiodism should not be readily apparent. Despite this, domestic breeds often show reduced piglet numbers and a slow return to oestrus under long-day conditions.

When photoperiodic effects on seasonality are discussed in relation to modern pig genotypes, there is often a degree of scepticism from producers, advisers and the scientific community. It is frequently suggested that “modern genotypes have progressed so far from the wild boar”. This is true in many respects. However, domestic pigs show similar nocturnal rises in melatonin to European wild boar (see Figure 7).[90] Thus, domestic pigs have the capacity to be photoresponsive and the potential to respond physiologically and behaviourally to changes in day length.



Pattern of light intensity (1x) = ▲ and mean (±SEM) serum melatonin concentrates (pg/ml) in European wild boars = ◆ and in domestic gilts = ■ over 1 48-h period.

Figure 7. Diurnal patterns in melatonin release from the wild boar (left) and a modern genotype gilt (right)[90]

One proposed pathway by which melatonin (and therefore photoperiod) affects sow fertility is via a reduction in production of luteinising hormone (LH) during long/increasing days, which is potentially amplified by restricted feeding post-insemination. This has a significant effect once the corpus luteum (CL), formed in the ovary after ovulation, becomes independent of pituitary support after day 12. A reduction in progesterone secretion causes a reduction in embryo-supporting secretions from the endometrium and the ability of the embryos to produce the second embryonic estrogen signal. This signal is essential to maintain the pregnancy after day 30. Inadequate embryonic signalling leads to regression of the CL and the pregnancy is terminated.[90]

Lighting and pig production

Breeding pigs

Standard or frequently advised 'best' practice for indoor pig units is to house service animals under 300 lux (at sow eye level) for 16 hours per day. This potentially contradicts the animals' biological optimum for breeding (as short, or decreasing day breeders; see **Seasonality in modern pigs** for more detail) and has possibly developed to help eliminate the seasonal troughs and peaks in fertility seen in indoor units caused by varying light lengths. However, a growing body of evidence suggests this is not optimum for fertility.

Effects of photoperiod on fertility

Gilts and sows

If domestic pigs follow the reproductive patterns of wild boar, sows should be stimulated by short (or decreasing) day lengths (autumn/winter breeders). Gilts have been shown to take longer to reach puberty during the summer(91, 92) or long day lengths(93) and reach puberty more rapidly under a regime of shortening day lengths.(94) Diekman et al.(95) showed that gilts on short day lengths with supplemental melatonin (thus mimicking shorter day lengths) and, therefore, autumn/winter photoperiods reached puberty faster. Claus and Weiler(96) found that decreasing the photoperiod by 20 minutes per week reduced the seasonal increase of wean-to-oestrus interval (5.7 days compared with 23.6 days in controls).

However, the literature reveals contradictory findings on the effects of photoperiod on reproductive success in gilts and sows. Sohst(97) found seasonal effects of lighting on gilts but not sows. In sows, long photoperiods (e.g. 16 L versus 1 L) reduced the number of days to next oestrus from weaning.(93) Even keeping sows in 24-hour darkness has been shown to improve their conception rate compared with 8-hour and 16-hour day lengths.(98) In contrast, continuous lighting caused sows to stay in oestrus longer than sows under 12-hour or 0-hour light regimes, but did not affect the number of days to oestrus from weaning.(99)

More recently, Chokoe and Siebrits(100) examined seasonality and photoperiod effects on sow fertility. All sows were farrowed under 'normal' day length conditions, with treatment animals being transferred into the 'restricted photoperiod' at weaning. Heavy lightproof curtains were used to occlude natural light and provide a continuous year-round reduced photoperiod (a 'restricted photoperiod' of 10L:14D), while control sows received natural lighting (10.4 L in winter and 13.4 L in the summer). The farrowing rate of sows served in early summer was significantly higher for those in the restricted photoperiod group (95.4%) than those under natural light conditions (80.8%). For the late summer-breeding sows, there was no significant difference in farrowing rate. However, the number of piglets born alive was significantly higher in the restricted photoperiod group than in the naturally lit group. As an overall treatment (taking early summer, late summer and winter breeding animals into account), restricted photoperiod demonstrated a significant effect on increasing litter size (12.1 versus 11.7).

Some of the differences may be associated with pigs' continued development; breeds from the 1970s may have different physiological characteristics from those from the 2000s, as well as taking different lengths of time to reach maturity. Gradual improvements in scientific understanding and approaches should also not be overlooked when assessing/comparing experiments.

Melatonin treatments for improved fertility

Bassett et al.(101) determined that if outdoor sows were administered with a 180 mg dose of melatonin via subcutaneous implant at the spring equinox (22 March), they exhibited no signs of the seasonal anoestrus observed in the control group. The timing of the administration of the implant was also critical to its effect on seasonal infertility. Implants administered later in the year (12 April or 22 May) had no significant impact on seasonal infertility. This suggests that (as has been observed in seasonality experiments with other species) there is a 'tipping point' after which the animal's endocrine system (via the increasing or decreasing concentration in melatonin) determines that the seasonal change has occurred and a hormonal cascade has already been initiated.

In the same study, melatonin was also administered in-feed; this was found to have no effect on performance or seasonal anoestrus. Possibly, this is because of the nature of melatonin and the potential for it to be denatured in the stomach. It is also possible that orally administered melatonin has no suitable pathway to affect the animal's blood plasma melatonin levels.

Boars

Studies on boars show that puberty is reached more rapidly under a regime of shortening day length.(102) In mature boars (both domestic and wild), decreasing photoperiod and short day lengths lead to an increase in plasma testosterone,(103, 104) spermatogenesis,(104) and activity and aggression.(105) Weiler et al.(103) observed that, at the peak of testosterone production, wild boar refused food for several weeks, leading to 25% weight loss. Artificial lighting with changing photoperiods (1,400 lux, both spring and autumn) resulted in lower reproductive organ weight, lower skatole and lower lean meat compared with natural lighting, suggesting some influence of illuminance or wavelength.(104)

Sancho et al.(106) found lower reproductive capacity in boars kept under complete darkness compared with those kept under 24-hour light and 12-hour light. However, sperm parameters did not always coincide with fertility. The seasonal effects on sow fertility cannot be ruled out in this work; sows were inseminated from the 24 L and 0 L groups in October and December, but from 12 L males in March and May.

Knecht et al.(107) examined the effect of increasing or decreasing photoperiod on various boar semen quality parameters. Lighting was provided via windows (no artificial lighting used). Increasing photoperiod was defined as January–June and decreasing photoperiod was defined as July–December. Photoperiod had a significant effect on semen volume per ejaculation, with the decreasing photoperiod group producing an additional 17 ml per ejaculation. There was also a significant effect of photoperiod on the total number of motile sperm per ejaculation, with decreasing photoperiod animals having, on average, 3.26×10^9 more motile sperm per ejaculation. This study shows a clear seasonal fertility bias in the modern pig driven by photoperiod and suggests that breeding boars should be kept in decreasing or reduced photoperiods prior to mating.

Seasonal infertility – temperature versus day length

Numerous studies examining the causes of seasonal infertility in sows have suggested that photoperiod, not heat stress, is the major cause of the phenomenon.(81, 93, 108, 109) Peltoniemi et al.(92) summarised that:

> **"Seasonal infertility has been described across all the continents under a diversity of climatic conditions, yet the severity of the condition does not correlate with any of these variations in temperatures. The strongest argument against temperature being of great significance in the physiology of seasonal infertility is the fact that the duration of seasonal infertility period exceeds long beyond August, when temperatures have fallen, and the climatic conditions cannot be described by anything but cool in countries like Finland. Therefore, it can be suggested that temperature may not play a major role in the pathogenesis of seasonal infertility."**

In further support, Auvigne et al.(109) examined seasonal infertility across 5 years and four regions in France, specifically focusing on whether photoperiod or heat stress were the main drivers. They concluded that seasonal infertility did not vary from region to region, while the number of 'hot' days did. They also observed that, in 2007, a particularly cool summer, no decrease in seasonal infertility occurred. Interestingly, during 2003 (a particularly hot year), they observed an additive effect of heat stress on infertility. They concluded that there was a "prominent role of photoperiod in seasonal infertility and of an additional role of heat stress in the hottest years". Furthermore, heat stress on sows reduces the litter survival rate(81) and causes high lactational weight loss of sows.(93)

Effects of illuminance on breeding

The illuminance provided during the day must be sufficient to maintain a strong circadian rhythm while also not inhibiting melatonin production at night. Tast et al.[(71)] showed that increasing light intensities above 40 lux (to either 200 lux or 10,000 lux) had no effect on scotophase (night-time) secretion of melatonin in pigs, either on rhythmicity or blood plasma melatonin concentrations (which varied greatly between individuals regardless of treatment). From the perspective of maintaining fertility (and excluding other factors that affect health and welfare), the work of Tast et al. suggests that providing more than 40 lux (as opposed to best practice guidelines that suggest 300 lux) is a waste of electricity. The work of Tast et al[(71)] also goes some way towards explaining the occurrence of seasonal infertility on some indoor units. Unless all natural light has been occluded, these animals might be receiving a sufficient 'dose' of light from windows/doors/vents, etc., to supress melatonin secretion during the summer months – even if artificial lighting is turned off. It is also important to consider that, to achieve a uniform light level of 40 lux at pig eye level, it would be necessary to aim for a higher illuminance, to take into account darker spots in a building, shading from other animals and so on.

Diekman and Green[(110)] found no difference in the pattern of melatonin secretion in pre-pubertal and post-pubertal gilts housed under artificial lighting (700 lux) versus open-fronted housing (maximum 50,000 lux in full sunlight with a 2-month acclimatisation period). Diekman and Hoagland[(111)] found little effect of supplementary lighting (300 lux) on gilt maturation, whereas exposure of the gilts to boars had a significant effect.

More recent work on barrows suggests that illuminance might affect hormone production. Griffith and Minton[(112)] examined the effect of light intensity on the circadian profiles of melatonin, prolactin, adrenocorticotropic hormone (ACTH) and cortisol in 11 barrows. Both treatment and control animals were maintained under 8L:16D conditions. The control group was exposed to 113 lux and the treatment group were exposed to 1,783 lux at 65 cm above floor level (both treatments used fluorescent tubes). Before commencing the trial, pigs had been kept outdoors (no times of year, or details of latitude or longitude were given), but were allowed 20 days to acclimatise to their new photoperiod/luminal intensity. Plasma prolactin concentrations were significantly higher at all sampling points for the treatment (higher light intensity) animals and night-time (but not daytime) concentrations of melatonin were significantly higher. The effect of higher intensity light observed in this trial may go some way to explaining the confusion in the literature surrounding the measurements of circadian rhythmicity in pigs. If the increased prolactin concentration observed under greater light intensity also occurs in gilts/sows, it suggests that the current practice of placing weaned sows under 300 lux of light and a 16L:8D photoperiod may encourage lactation to continue, which would be undesirable when trying to promote oestrus behaviour and a return to normal reproductive cycling in the breeding sow. Taya and Greenwald[(113)] demonstrated the suppression of ovarian follicular development and therefore ovulation, by prolactin in rats. However, this link is more widely debated in pigs and high illuminances (e.g. 400, 500 and 700 lux, but not 50 lux) have been reported to reduce the number of days to next oestrus from weaning.[(114)]

Effects of spectrum on breeding

Gilts and sows

Hannesson[(115)] found no significant effects of four conventional spectra (HPS, MH, HPS + MH and fluorescent, illuminance unstated) on breeding success in gilts. Similar proportions of gilts reached puberty in each group, reached puberty at a similar age and had similar ovulation and embryo survival rates. However, the low colour-rendering properties of the HPS bulbs limited success in detecting changes in redness in the vulva, thereby limiting its application in breeding and farrowing housings and possibly affecting the results of the study.

Grower–finisher pigs

It is widely accepted that the development of the growing herd begins in the farrowing crate or even before this, *in utero*. Where gestating and lactating sows are housed under different lighting regimes, it is often hard to distinguish whether the sow is directly affected by the lighting and the piglets indirectly affected, or if the piglets are directly affected. Effects might include improved litter size and measurements such as milk yield and suckling behaviour.

Effect of photoperiod on growth and the finishing herd

Sows and piglets

Piglets benefit from longer photoperiods (16 L versus 8 L), with heavier, healthier piglets (still significantly different at 10 weeks of age) and more piglets per litter.[116, 117] Simitzis et al.[118] examined the effect of extending the farrowing house photoperiod from 8L:16D to 20L:4D on piglet behaviour and growth. The 20L:4D group had increased feed intakes, increased weights at weaning (while weights at 2 days of age were not significantly different) and were more 'resistive' during a back test. The increased photoperiod had no significant effects on sow behaviour (specifically, on the interval between nursing bouts, duration of nursing bouts or on sow sitting, standing or lying durations).

Cunningham et al.[119] showed that increasing photoperiod does not increase prolactin production in the sow. It is likely that changes in milk properties are a result of more suckling activity by the piglets. Niekamp et al.[116] showed that beneficial effects of long photoperiod on the sow (16 L) can affect piglet immune response, at least until piglets were 21 days old. Short day length during late gestation in the sow is thought to contribute to increased litter size and survivability of the piglets.[117] Hälli et al.[120], on the other hand, found little difference between short-day (10 L) and long-day (14 L) photoperiods on sows and farrowing parameters. A lower farrowing rate during the summer months of the trial suggests that the effect of season is multifactorial and not influenced by lighting regime alone.

Increasing the number of hours of illumination per day (up to 18 hours), thus mimicking a spring birth, might benefit piglets, resulting in improved body weight gain and wellbeing.[121] Claus and Weiler[96] showed that increasing the hours of light per day (up to 15–16 hours) had little effect on sow parameters, but increased piglets' suckling frequency increased the survival of low-birth weight piglets. Provision of a longer photoperiod is, therefore, linked to higher piglet suckling activity and affects milk quality and production by the sow.

Weaners

Bruininx et al.[122] showed that, in weaned pigs, a long photoperiod (23L:1D) improved their food intake and energy metabolism. They suggested that increasing lighting post-weaning might stimulate post-weaning feed intake. However, it is important to note that, during the first week (when the lack of feed intake is most pronounced and is partly responsible for the 'post-weaning dip'), there were no significant effects on any performance parameters. Reiners et al.[123] also found that, compared with an 8L:16D regime, a 20L:4D photoperiod had no significant effect on performance parameters in the 4 days immediately post-weaning, or any effect on performance during the entire nursery period. Better immune responses have been found in weaned pigs given longer day lengths (up to 18 hours),[124] alongside improved feed intake and average daily gain (at 44 lux).[125] Similar results were also found by Niekamp et al.[116], with improved health and weight in 16 L piglets still significantly different from 8 L piglets at 10 weeks of age. Lay et al.[16] found that 24-day-old, newly weaned pigs were more active under continuous lighting than under a 12L:12D regime. However, the piglets showed more agonistic interactions, suggesting reduced welfare under these conditions.[126] It has been demonstrated that most of the weaner pigs did not start eating during dark periods of the day, with best results observed for 24 L (though legislation currently prohibits this treatment) immediately following weaning.[126]

Grower-finisher pigs

Legislation currently prohibits the commercial rearing of pigs in continuous dark or light conditions, but the effects of this have been examined in scientific trials. Adam and Telaki[127] found that pigs reared in complete darkness had improved weight gain and a better feed conversion rate, but higher carcase fat content than pigs kept under 24-hour light. Braude et al.[128] found similar results. However, the opposite was found by Hacker, et al.,[129] with gilts in continuous darkness showing a lower daily gain than controls (12L:12D). If these results are comparable, then combining them suggests that a 12L:12D regime led to better productivity than 24 D, which was better than 24 L. Dureau et al.[61] kept minipigs under a continuous light intensity of 2,500 lux for up to 12 weeks. One result obtained was that animals experiencing 4 or more weeks of continuous illuminance lost up to 20% of their body weight, indicating either behavioural disinclination to eat, possibly because of discomfort, or stress associated with the extreme lighting conditions. Neither the pig breed nor experimental conditions are commercially (or legally) relevant, it nevertheless demonstrates the negative effects of suboptimal lighting on welfare and growth.

Martelli et al.[130] explored the effects of two alternative artificial photoperiods (14L:10D and 8L:16D) on the growth and behaviours of 56 'heavy' barrows (Large White X Landrace) in Italian ham production. The pigs, who were kept in fully slatted accommodation, were enrolled on the trial at an average liveweight of 112.5 kg. Light intensity was 70 lux for both groups throughout the trial. The longer photoperiod (14L:10D) was found to produce a significant increase in daily liveweight gain (DLWG) and an improvement in feed conversion ratio (FCR), see Table 1. In a further study, Martelli et al.[131] examined the effect of 16L:8D versus 8L:16D on the growth rate of heavy pigs. As in the previous study, the longer photoperiods improved DLWG and FCR, although the improvements were slightly lower (Table 1). DLWG, both from day 1–155 and from day 1–251, increased by 66 g/day and 46 g/day, respectively. In both experiments, animals had increased recumbency and significantly reduced rooting behaviour. This shows that not only can altered lighting regimens capture additional growth in existing systems, but that there is also an opportunity to improve gain:feed ratios (FCR) by ensuring the proper application of lighting to an existing production system.

Table 1. Summary of results from two photoperiod lighting trials with finisher pigs

	Martelli et al., 2005[109]	Martelli et al., 2015[110]
N/Treatment (total)	28 (56)	20 (40)
Treatment	14L:10D	16L:8D
Control	8L:16D	8L:16D
Weight achieved during trial	157–163 kg	95–105 kg
DLWG increase	98 g/day (20%)	66 g/day (15%)
FCR improvement	17%	10%

Feeding time

Cattle avoid eating in the dark, resulting in reduced milk production, liveweight and body condition, coincident with raised blood cortisol levels.[132] In pigs, feeding behaviour does not appear to be affected by illuminance, with feeding and weight gain still occurring in the dark.[128] Pigs given a choice of four illuminances (0.4, 4, 40 and 400 lux) in different chambers ate for similar lengths of time under all four illuminances.[133] Piglets showed greater suckling frequency and there was better survival of low birth weight piglets when kept in increasing hours of light.[96] Gadd[134] concluded that leaving the lights on for the first 24 hours post-weaning (though legislation currently prohibits this treatment) enables the more submissive animals to begin feeding.

Boumans et al.[135] used 'simulated' pigs to demonstrate the importance of circadian hormone rhythmicity in pigs' daily feeding patterns. While this paper used computer-modelled pigs rather than live animals, the models incorporated a large quantity of published data on hormone profiles and behaviour of pigs linked to their daily feed intake patterns. They considered that "circadian rhythms in melatonin and cortisol might explain the 'alterans' feeding pattern of pigs". An alterans feeding pattern is one in which a small peak of feed intake is seen at the beginning of the day and a larger peak at the end of the day. The authors also suggested that "cortisol and melatonin play a role in the causation of the bigeminus feeding pattern" seen in other animals, where the first peak in feeding is higher than the second one of the day. This implies that, by altering these circulating hormones or their rhythmicity, we may be able to manipulate feed intake behaviour. Altering either photoperiod or luminal intensity would allow modification of the circulating concentrations of these hormones and their rhythms in production animals, without needing to administer exogenous hormones.

Effects of illuminance on growth

Farrowing sows and piglets

Sows under lower illuminances (2–6 lux and 10 lux) produced lighter and fewer piglets than sows under 70–100 lux.[136] Illuminance was associated with position within the farrowing house during this experiment, so it is possible that temperature and ventilation were allied with the illuminances. Mutton[114] found no difference in piglet birth weights, weaning weights, pre-weaning mortality or growth rate of piglets raised under four illuminances (40–583 lux) under an 18L:6D photoperiod. The effects of higher illuminances have not been reported in these circumstances; potentially, welfare may continue to increase with higher illuminances, or may decrease following an optimum within 40–583 lux.

Grower–finisher pigs

Martelli et al.[137] described the effects of two light intensities (40 lux or 80 lux) under a 12L:12D cycle on production and behavioural traits of heavy pigs (from 75 kg liveweight to 160 kg liveweight at slaughter). The greater light intensity had no significant effect on either performance (DLWG or FCR) or slaughter (KO%, P2, lean meat %) characteristics of the pigs. Pigs under the higher light intensity showed significantly reduced lateral recumbency and (which will no doubt be partially linked to this reduction) significantly increased sternal recumbency. Drinking frequency was also significantly lower in the high light treatment. Pigs showed significantly fewer head-to-head interactions in the 80-lux group and a marked and significant reduction in agonistic interactions. Pigs in the 80-lux group also tended towards increasing nose-to-nose interactions; this paper considered this interaction to be a social/tactile and non-agonistic interaction. Effectively, Martelli et al.[137] suggest that increasing light intensity from the legal minimum of 40 lux to 80 lux had no negative impact on growth/meat parameters, but improved behaviour and reduced negative interactions between the animals.

Effect of spectrum on growth

Sows and piglets

While lower stress responses at weaning were found in piglets housed under natural light compared with artificial lighting, these environments also differed in illuminance and photoperiod.[138] The authors note that differences in cortisol measurements between the groups may be attributed to the differently perceived time of day caused by the different onset of photoperiod.

Grower–finisher pigs

Rearing under 65-lux red light[64] produced similar results to rearing under constant darkness,[139] with heavier body weights and improved daily gain in these groups compared with those under 65-lux UV, 500-lux cool white fluorescent lights and 650-lux daylight on a 16L:8D schedule.[64] The two 65-lux environments are unlikely to match in brightness because of variations in the range of wavelengths presented. This result is likely to be associated with the animals' reduced perception of red wavelengths; the pineal glands of the two groups developed similarly, suggesting the effect was caused by a lack of perception of the light source[64] and confirmed behaviourally by pigs' difficulty in detecting 694-nm light sources.[15]

A recent AHDB Pork pilot study,[49] which examined the use of specified wavelength LED lighting (SWL, in this case blue) in weaner and grower–finisher pigs, gathered preliminary (anecdotal) evidence that using SWL in pig buildings may affect behaviour and vices and, therefore, welfare. While these results are far from conclusive, they do support the need for further trials on this topic.

Boar taint

Boar taint is caused by the accumulation of androstenone (a male hormone) and skatole (a by-product of gut bacteria) in the fat of male pigs. Lower levels of boar taint are found in pasture-reared animals; lighting conditions on pasture will not only show a wider range of illuminance levels (including much higher values) and photoperiods than housed conditions, but will also have a wider spectral range.[104]

However, there are many other differences between outdoor and indoor environments and husbandry factors that may also affect this. Wild boar are considered to have significantly higher levels of boar taint than commercial breeds,[140] thus environmental factors (including light) are probably of lower relevance than animal genetics.[141] This is further supported by the fact that different breeds[142] and individual sires[142, 143] have different magnitudes of boar taint.

Spring lighting (440-lux natural light) has been shown to increase androstenone.[105] Skatole levels in entire males in the UK, Sweden and the Netherlands were higher in winter than in summer, but no change was found in Danish, French and Spanish pigs. While androstenone levels were higher in winter in the Netherlands, androstenone levels decreased in the UK population (no changes in the other countries studied).[144] The systems donating the pigs are not described, so photoperiod itself may not be so relevant as seasonal changes to other environmental factors and different systems may be differentially affected by changes in weather, external temperature, etc.

The influence of light on behaviour and welfare

Lighting can have both direct (visual) and indirect (circadian and hormonal) effects on animal behaviour and welfare. Behavioural measures should be interpreted with care; for example, a pig might lie down more because it is relaxed and comfortable, or it may be showing passive coping or learned helplessness.[146]

Visual behaviours

Pigs are highly social, hierarchical animals and, as such, require some form of communication and individual or group recognition, both to keep the group together and to maintain the hierarchy without repeated fighting.[147] Olfactory and auditory cues are normally used, but communication also includes a variety of visual signals, involving general posture and specific positions of the tail, ears or head.[30] Aggressive animals may perform a parallel walking display, which is likely to include some form of visual assessment.[148] Males of various wild pig species have visible structures, such as hair tufts on the ear, cheek or snout, wart-like skin outgrowths and contrasting patterns of hair and hair colours,[164] which probably help to communicate reproductive fitness or fighting instincts. McLeman et al.[148] and O'Connor et al.[149] showed that pigs can discriminate between conspecifics using vision alone. Since many of these visual structures are not observed in the domestic pig,[150] they may not be able to communicate visually so well.

Wild boar show vigilance behaviours, especially when feeding as a group with young.[151, 152] Wolves hunting wild boar approach from downwind, so because the boar's well-developed olfactory senses are unable to detect their advance, they rely on vision instead. In commercial farming, visual detection of predators is less important. However, pigs do still perform vigilance behaviour, so denying them the ability to see possible threats at a distance could compromise their welfare and induce stress.

Social learning also indicates the use of vision: pigs can learn the position of food, the colour of their food trough and a degree of panel pressing from observing siblings (during 10 daily sessions, pigs observed a trained sibling demonstrator pressing one of two panels for a food reward and were compared with pigs exposed to panels without a sibling demonstrator).[159] Pigs also wait until they are out of the line of sight of a more dominant individual when locating a known food source to avoid possible conflict.[153] Broom et al.[154] showed that pigs can learn the location of a food source using mirrors. Done et al.[155] showed that pigs prefer to feed from larger food containers, even if less food is present. Various operant experiments have shown that pigs can learn to associate a visual cue with a food reward.[41,42,156,157] Thus, vision has some role in foraging, even if light per se is not vital for feeding.[158]

Responses to colour

Pigs can recognise and associate a colour with a food source.[159, 157] Experiments with dyed grains showed that the pigs preferred blue over green and black food.[160] Avoidance of this same colouring at higher concentrations suggests that the original preference was probably for colour rather than any flavour of the dye. Hutson et al.[161] suggest that sows were neophobic to blue food. Both experiments suggest that pigs can perceive blue wavelengths as being somehow different to the other dark colours used, assuming the scent of the dye was not an issue.

Pigs showed a consistent startle response to the warning colours of black and yellow, although this might reflect detection of the high-contrast patterns rather than the colours.[161] Jankevicius and Widowski[162] compared the attraction between artificial 'tails' soaked in blood, saline or dye to investigate pigs' preference for factors of bitten tails. The colour of the tails, created by different concentrations of the same dye, had no effect on the attractiveness of the cue to the pig; thus, unlike chickens,[165] pigs do not appear to be attracted to wounds on other animals by the visual appearance of blood.

Activity and day length

In general, longer photoperiods are associated with increased activity in pigs. Lower activity is reported in pigs raised under continuous darkness[139] than in pigs raised under 12L:12D.

Weaned pigs raised under 24L:0D showed higher overall levels of activity throughout the 24-hour period than controls under 12L:12D. However, increased activity was attributed to more agonistic encounters and social stress, suggesting that continuous light is a stressor.[16] Van Putten[13] was unable to demonstrate that the behavioural repertoire of pigs – and indirectly their welfare – was affected by the presence or absence of light. Piglets raised under 120 lux in an intermittent pattern (6 × 1L:3D) showed higher levels of activity than those raised under lower illuminances. However, immunological and biochemical analysis of blood showed that these animals were less healthy, indicating potentially poor welfare conditions.[126] Intermittent lighting conditions have rarely been studied in pigs, reducing the opportunity for further comparisons.

Behaviour and welfare

Fear and anxiety

Fear is one of the 'Five Freedoms': "all animals should be free from fear".[20] Rats handled under red light are calmer and exhibit behaviour similar to when they are handled or housed in darkness.[166, 167] Phillips and Lomas[168] concluded that calves were more fearful under green light than red or blue light, intended to be isoluminant to the animals. In rodents, fear is indicated spending time in lit and unlit compartments,[169] with rodents spending little time in the lit compartment compared with the dark, unless treated with diazepam to reduce fear.[160] However, in pigs, the relationship between light, dark and fear is less clear. Although 23/84 pigs showed a strong preference for the dark compartment, others occupied the lit compartment for an average of 29.5% of the available time. However, diazepam-treated pigs spent more time in the dark than the controls.[170] It is possible that pigs have a less innate fear of being in a lit area than rodents and that diazepam may affect their behaviour in some other way than reducing anxiety (e.g., inducing sleep).

Stereotypies

High levels of stereotypical performance are associated with poor welfare in the previous or current environment and several stereotypies have been observed in pigs.[172] Lighting may indirectly trigger bouts of stereotypy in pigs as an indication of the imminent arrival of, or prevention of access to, food. For example, tethered sows were observed to perform stereotypies associated with the beginning and end of the photoperiod.[171] The behaviours performed are probably derived from foraging or feeding attempts associated with food presentation during daylight hours rather than being triggered by light, per se.

Fighting

Fighting between pigs during mixing results in injury and stress, commercial loss and reduced welfare.[173] The effects of light on this behaviour are contradictory. No differences were found between mixing at 5 lux or 100 lux[174] and applying opaque lenses to the pigs (thus reducing their vision) did not affect the formation of social groups.[30] This suggests that vision may not play a principal role in fighting or communication of signals surrouning fighting, even though various visual signals exist.[30] Potentially, the intense nature of the introductions, for example, reduced flight space and inability of subordinate pigs to escape, makes these signals ineffective in commercial situations. Work by Barnett et al.,[175, 176] however, found that introducing new pigs in the dark was comparable with treating pigs with an anti-aggression drug, amperozide, with fewer aggressive encounters upon introduction.

There are several explanations for these differences:

1. Pigs were kept under a continuous environment of either 5 lux or 100 lux after mixing; continuous lighting may have been unfamiliar to the test pigs, thus causing stress, or the continuous nature of the lighting may have resulted in pigs' irritability. Either of these scenarios could have increased the likelihood of aggression.[175]
2. Barnett's pigs were grouped not just in the dark, but after dark, after a second bout of feeding when they would normally be settling down to sleep.[176] The timing of the mixing may have affected these results because the pigs were already satiated and preparing for rest, thus were less likely to fight. Food provision per se did not affect the incidence of fighting in Barnett's work, with controls including ad lib feeding after mixing.

Preference for light conditions

The most basic preference is between light and darkness; Hacker et al.[177] found that when growing pigs were given a continuous choice between an illuminated and a dark compartment, they spent most time in the dark (75%). However, they showed no clear circadian rhythm of preference, with short bouts in each compartment (1.83 hours in the dark versus 0.82 h in the light) and an average of more than 10 transitions between the compartments in a 24-hour period. Observing the pigs showed that they preferred to eat in the lit compartment (illuminance and light source were not specified). Juvenile pigs (7 weeks and 11 weeks old) given a choice between <4, 4, 40 and 400 lux, showed a clear preference to spend time in the <4 lux compartment, mainly because of sleeping/resting behaviour. Similar proportions of their active time, including eating and drinking, were spent in all illuminances.[21] Whether pigs chose to enter the dimmest compartment to sleep, or whether sleep was induced by entering the dimmest environment, cannot be resolved from this work. Tanida et al.[178] investigated the behavioural responses of piglets to darkness and shadows. One-week-old piglets were isolated in a test box and their response to access to an adjacent test box with a different light environment was measured. All combinations of access to dark and light were used, additionally going from dark, to dark plus a dazzling light beam and into dark with a light beam from behind the piglet. The lighting used to create the bright environments was 2,100 lux at piglet eye level, compared with dark at 5 lux or the beams at 160 lux. The authors concluded that piglets significantly feared staying in darkness, tending to move towards brightly lit areas (in contrast to deer held in isolation)[179] and were also frightened by spotlights and the painted black and white patterns.

Preference for familiarity

In choice situations, pigs and piglets often seem to prefer a lighting environment that is similar to their home pen. While it is possible that the animal's eyesight adapts to its home pen lighting, it is more likely to be due associated with the animal's familiarity with that environment and preference to return 'home' from a novel or isolated environment. Piglets offered a choice of illuminances in creep areas were more likely to select their home pen lighting and that light was neither strongly attractive nor aversive.[180] The experiment specifically used piglets from different rearing illuminances to factor this potential bias into the analysis. It is therefore possible that piglets in the work by Tanida et al.[178] may have selected a 'bright' environment with an illuminace similar to that of their home pen (lit with artificial and natural light). This behaviour may have been unintentionally influenced by the previous use of nursing grunt recordings to encourage the pigs to enter the alternate compartment. Newborn piglets were able to distinguish between bright, dim and dark environments, preferring dim and dark to bright light. Illuminances were 11, 5.5 and 2.8 lux in the test compartments, with the start box described as "darker". All three illuminances could be described as dim, but piglets still showed a preference.[181]

Phillips et al.[182] investigated whether illuminance affected pigs' preferred environment for walking up ramps. While no significant effect was found, the authors noted that the illuminance closest to the pigs' home pen environment (80 lux) was preferred. Preference tests can only be accurately interpreted when the options available cover a suitable variety of environments and where options for which there is no natural correlate are avoided. The animal may also only be able to select an environment for its short-term occupation; if it was aware it would be confined in its selected environment for an hour, it may learn to select differently from occupancy durations of 5 minutes or a week. Pigs can show a degree of time appreciation;[184] preference experiments could therefore be combined with prior training on length of confinement [183] to give a more detailed picture of pigs' preferences for different periods of light.

Growing pigs in a preference chamber showed no differentiation between illuminances of <4, 4, 40 and 400 lux when active, eating and drinking similarly (~1.16 hours per day) in all compartments.[133] Results from this study showed that the pigs preferred to dung in more brightly lit environments, probably because they rest in dimly lit ones. When pen layouts are being designed, it may be preferable to provide dimmer lighting over the resting area and brighter lighting over the dunging area, but the effectiveness of this will depend on the illuminance levels provided.

Motivation experiments

Motivational measurements, in which the animal must work to achieve an outcome, can indicate how important that environment (or resource) is to the animal – and this is more likely to reflect a behavioural or physiological need than just a preference. While preference is generally measured as time spent in each environment, or as number of times of entry to each compartment each time the subjects are removed, the animal's distribution of its time may change if the resource is given a cost.[(163)] Five minutes per day of access to 100 lux may be as important to a species as 9 hours of darkness, but this cannot be determined in free-choice experiments. Many experimental factors potentially affect the preference measured; for example, stocking density, age, sex, duration of occupancy of the animals. A series of motivation studies by Baldwin and Meese[(185)] showed that when pigs were able to switch lights on for brief periods (up to 20 seconds per activation), the light (350 lux) was kept on for less than 1% of the time. This indicates that pigs' motivation was weak and/or the animals preferred to be doing activities other than controlling light onset. When the animals could switch their pen lights both on and off, the lights were kept on for approximately 72% of the time, with some proportion of each hour unlit, but no long periods without light. Baldwin and Meese[(185)] concluded that pigs showed a strong preference for light over darkness, despite light onset being only weakly reinforcing. Again, these results may demonstrate pigs' preferences for home pen lighting. Additionally, the onset of 350 lux in an otherwise dark environment may have been aversive because of the initial glare, thus explaining why motivation to turn the light on was weak, even though a lit environment was preferred. The effect of anosmia (lack of ability to smell) on this preference was also examined, but there was no significant effect on the amount of light obtained – reduction in sense of smell did not increase pigs' reliance on visual information.

Summary

This review has covered a breadth of material and has sought to consider, critique and present all available literature for lighting in pigs, both from a behavioural point of view and from optimising production.

An industry debate exists that pigs demonstrate no circadian rhythm in melatonin. This view seems to be largely linked to early papers in which no rhythm was established or no melatonin was detected. Given that several papers discussed in this review show clear circadian rhythms in several pig hormones, including melatonin, it now seems likely that the methodology and assays used in these early studies lacked the accuracy and specificity needed to detect such rhythms.

Behaviour

In terms of behaviour, it is clear from the review that to truly understand how pigs respond to changes in light intensity or wavelength (i.e., altering the colour of visible light or the inclusion of light/EM radiation that falls outside of the visible spectrum) requires more work. Taylor's work,(15) which looked at the behaviour of pigs in a preference chamber, reveals that pigs have a clear preference for sleeping in the dark and for dunging in lit areas. It remains unclear, however, if the preference for dunging in brightly lit areas is an outcome related to the preference for sleeping in dark areas, as was specifically raised by Taylor.(15) It is also important to consider how this behaviour may be extrapolated to large straw yards or traditional slatted and fan-ventilated buildings. It certainly suggests that one uniform level of lighting across a building might not be desirable, particularly in 'dung passage' style buildings with solid floors and straw, in which we would seek to entrain pigs to dung in the scrape-through passages and sleep on the straw. Perhaps this could be achieved by having differently lit zones? Further research is needed to explore this hypothesis and potentially effect a change in the legislation around minimum times for the absence of artificial light in pig housing.

Several research papers have suggested that increasing photoperiod pre-weaning and immediately post-weaning increased feed intakes, exploratory behaviour and the restiveness of piglets subjected to a back test. Further work might expand on research exploring the value of continuously lighting pigs for 48 hours immediately post-weaning, because previous work has demonstrated that this reduced the number of non-eaters – a factor becoming more important with the reduction in antimicrobials and the impending loss of zinc for post-weaning diarrhoea control.

The paper by Martelli et al.,(137) which showed that by increasing light intensity from 40 lux to 80 lux in a production environment it is possible to reduce agonistic interactions between pigs, suggests that there is value in conducting more in-depth, large-scale studies to explore optimal lighting intensities for reducing undesirable behaviour. This is, however, the only paper so far to have explored the effect of intensity on pig behaviour in an environment representative of any commercial production system.

Sow productivity

While there is some conflict in the papers reviewed regarding the effect of photoperiod on sow productivity and seasonal infertility, there is too much evidence in favour of its effect to dismiss it out of hand.

The improvements seen in sow reproductive performance during the study conducted by Chokoe and Siebrits(100) is difficult to ignore, as is the work by Bassett et al., which demonstrated that timely implantation of exogenous melatonin (or a synthetic analogue thereof) entirely removed the seasonal infertility seen in the control group of an outdoor herd – even though no effect was seen when melatonin was included within the diet of a third group during the same study.

Work reviewing the interaction between temperature and photoperiod on seasonal infertility is wide-ranging in both its methodologies and the ultimate conclusions drawn. The one clear outcome from this is that more work is needed. Further meta-analysis is unlikely to be conclusive, whereas a fully controlled, properly replicated biological in vivo study conducted on a representative unit may provide a clearer answer as to the effect of photoperiod on sow performance/seasonal infertility in the English herd.

The current recommendation to expose pigs to 16 hours of light at 300 lux at floor level, which currently pervades the industry, does not, perhaps, optimise fertility on farm (and may in fact have a negative impact). However, it is a clear indication that industry advisors recognise the role of photoperiod (at least in indoor herds) in sow fertility.

Growing and finishing herd productivity

There is less literature published on the effects of either photoperiod or intensity on the performance of growing or finishing pig performance – not just in commercially representative facilities, but in any context. As previously mentioned, only one published paper was found to explore the effect of luminous intensity on grower–finisher pigs in a commercial setting. This paper was also published in a little-known German veterinary journal, which may explain why it is absent from some previous literature reviews.

Two papers were found[130, 131] to explore the effect of photoperiod on grower–finisher performance. Both papers found that pigs performed better, in terms of both FCR and DLWG, under longer photoperiods (in one case 14L:10D and in the other 16L:8D) than under the legal minimum of 8L:16D (which, anecdotally, would be the most common photoperiod in place on farm in the UK).

Further work

Based on the literature presented in this review, it is suggested to pursue further work in the following order of importance:

1. Optimal photoperiod for grower and finisher pigs.
2. Optimal photoperiods and transitions between the same for indoor sow productivity in the UK – including a comparison of 300 lux and a sensible alternative during the wean-to-service interval (not strictly photoperiod but relevant to this specific area). This work would need to include in-depth hormone profiling to understand the effects of these optimised photoperiods and the axis the change is acting upon from an endocrinological standpoint.
3. How do the photoperiods deployed in point 2 affect the progeny of these animals, either in finishing or further breeding as replacement?
4. Optimal photoperiod for nursery pigs (both immediately post-weaning and in the longer term).
5. Optimal luminous intensity for grower–finishers.
6. Optimal luminous intensity for all stages of sow production.
7. Deploying the learning from point 2 to explore opportunities to optimise outdoor fertility.

While work on wavelength is also extremely interesting, little evidence exists at present, so this would only become a priority once the above questions are addressed.

What should we do for now?

The literature points towards potentially:

- Higher levels of luminous intensity in finishers (such as 80 lux, which is the legal minimum in Germany)
- Longer than the legal minimum of 8L:16D photoperiods in finishers (14/16L:10/8D)
- In sows, an approach of:
    a. 16L:8D in farrowing, ramping down to 8L:16D in the last week of lactation
    b. 8L:16D in weaning to service and dry sows
    c. Ramping back up towards 16L:8D during the final weeks of pregnancy

However, none of the outcomes from the review are conclusive, so anyone pursuing these guidelines does so entirely at their own risk and with little evidence to advocate real changes.

What is clear from anecdotal evidence is that 40 lux, the legal minimum, is not actually (as is sometimes suggested) “enough light to read a newspaper”; buildings can seem relatively ‘light’ and have a light intensity sub-10 lux.

The final message: think about light, measure it, make sure any new installations have timers fitted and provide maximum possible uniformity, at whatever level of luminous intensity you opt for.

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Glossary

Barrow – a castrated domestic male pig

Boar – an uncastrated domestic male pig

Circadian rhythm – a biological process that displays an endogenous, entrainable oscillation with a period of approximately 24 hours

Creep – a section within a farrowing pen that a sow cannot access. Can also refer to early-stage piglet/weaner feed (i.e., ‘creep feed’)

Cone cells – light-sensitive cells found in the retina of the eye that enable colour vision

Conspecific – a member of the same species

Crepuscular – active in twilight

Daily light integral (DLI) – the total amount of light received at a location during a 24-hour period. The DLI is influenced by both the day length (photoperiod) and the intensity of the light

Diurnal – of, or during, the day

Domestic pig – *Sus scrofa domesticus*, also known by the shortened name *Sus domesticus*

European wild boar – *Sus scrofa*

Foot-candle – measure of illuminance, which is 1 lumen falling on each square foot of receiving surface

Gilt – a female pig that has never been pregnant or is pregnant for the first time

Illuminance – a measure of the amount of light falling on and spreading over (illuminating) a surface area

Intensity – a measure of the brightness of light

Isoluminant – a colour display in which the component colours have been so carefully equated in luminance that they stimulate only colour-sensitive perceptual mechanisms and not luminance-sensitive mechanisms

Melanopsin – a photoreceptor in the eye that detects blue light, which helps entrain the circadian rhythm

Melatonin – a hormone that is important in maintaining sleep/wake cycles

Pineal gland – the gland that produces melatonin

Pituitary gland – a gland that produces several hormones that are important for regulating stress, growth, reproduction and lactation

Primiparous – pregnant for the first time, or having given birth to only one litter

Photoperiod – the period of the day when an organism receives illumination. The photoperiod differs from daytime because it can be extended with artificial lighting or shortened by shading an organism from all sources of light

Zeitgeber – an external environmental cue (often light) that acts to entrain the circadian rhythm

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