Book Chapter

Analyzing and Modeling Environmental and Production Variables in Weaned Piglet Farms

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Abstract

Environmental variables and animal activity were analyzed to improve environmental control systems in conventional post weaning livestock buildings. Post weaning is a very sensitive phase in the rearing of piglets from 5 to 20 kg, mainly influenced by separation from the sow, mixing of litters and changes in diet or environment. For this reason, environmental requirements are

strict and changing. To achieve these requirements, livestock buildings have ventilation and heating systems, usually regulated by temperature-based controls. In addition to temperature, other important environmental variables include relative humidity, CO_2 and NH_3 concentrations. Other variables that characterize the state of the animal, such as animal activity, should be added to the environmental variables in order that indoor climate and animal behavior may serve as the basis for new environmental control strategies. Such strategies should contribute to achieving maximum performance with the lowest possible use of resources, while focusing on animal welfare and production efficiency.

Keywords

Indoor Climate; Temperature; CO_2 Concentration; NH_3 Concentration; Relative Humidity; Model; Weaned Piglets; Animal Activity; Environmental Control

Introduction

This chapter focuses on postweaning buildings, where weaned piglets are housed for about 40 days, during which their live weight increases from 6 to 20 kg. During postweaning, environmental control must be adapted to the growth needs of the piglets, and environmental variables must be maintained at optimum levels that will change according to the changes in requirements [1]. This is a sensitive phase for piglets [2], particularly directly after weaning, because weaning results in simultaneous stresses including separation from the sow, mixing of litters, changes in diet and environment [3,4], health status, dietary nutrient level and balance, palatability of ingredients, forms of diet presentation, water supply and quality, and stockmanship, which influence feed intake [5] and can affect both growth performance and intestinal health of piglets [6].

On intensive livestock farms, animals are directly exposed to air and, therefore, to air pollutants, which favor indirect effects such as the emergence of illnesses [7,8]. Temperature is the predominant environmental variable in livestock buildings. In addition to temperature control, environmental management comprises the maintenance of good air quality, characterized by relative humidity, concentration of gases such as CO_2 and NH_3, and presence of microorganisms in the air. Suitable environmental conditions must conform to the needs of the animals and consider animal state and behavior, which can be characterized by animal activity.

Therefore, environmental control inside livestock buildings further highlights the importance of continuously monitoring livestock production processes. Actually, developing real-time decision-making tools will allow producers to implement management changes while considering the likely economic consequences of such decisions [9]. New environmental control strategies may contribute to the achievement of maximum performance with the lowest possible use of resources, with special regard to animal welfare and production efficiency.

Temperature and Relative Humidity

Temperature is the most important comfort variable in indoor environments. A widely accepted range for the optimal thermal conditions of piglets is defined as the thermo-neutral zone (TNZ), which is the range of thermal environments with minimal metabolic rate [10, 11]. The limits of the TNZ are mostly expressed in air temperature, but air velocity is considered as an important factor too, as it is a component of convective heat loss and, therefore, of thermal comfort [3]. When the thermal environment of the piglet exceeds the limits of the TNZ, animal performance (feed intake, growth, feed conversion ratio) is expected to deteriorate [12] with an increased risk for animal health under certain circumstances.

In postweaning, the demand for heating energy is high [13] because of the high temperatures required for animal growth, which poses a risk of heat stress caused by high indoor temperatures in warm periods [14]. Recommended temperature values for weaned piglets housed in rooms with plastic slatted floors range from 30-32ºC for 5 kg live weight to 19-25ºC for 20 kg live weight [15]. Some authors [3] analyzed temperature requirements in three periods: the critical period (the first two weeks), the postcritical period (the following two weeks) and the final period. During the critical period, the lower-critical temperature must be in the range 26-28ºC [3], which can be reduced to 24ºC in the following two weeks [16]. During the final period, indoor temperature can be rapidly reduced by 2-3ºC per week until the final temperature in the finishing house is reached.

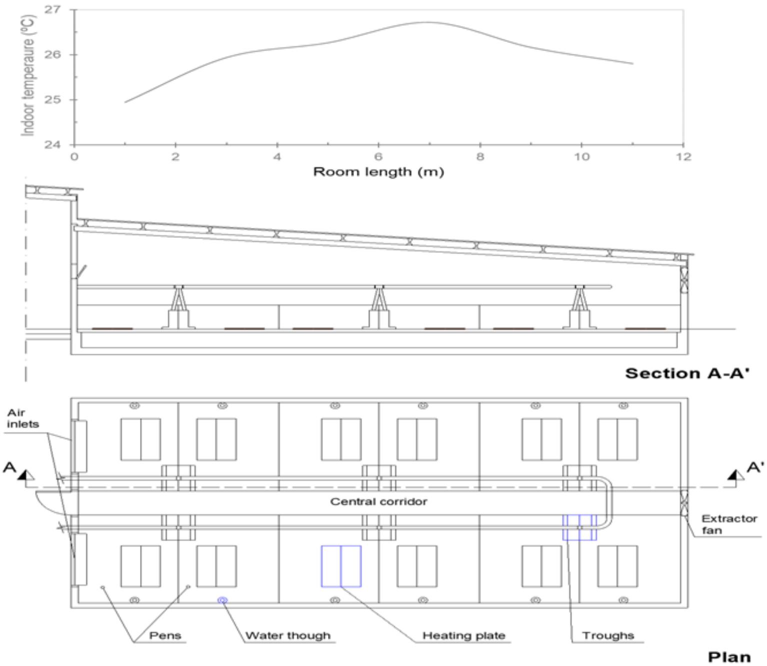

Figure 1: Plan, section and mean temperature profile along the pens for a year in a postweaning room, in a livestock building with a central corridor, air inlets at both sides of the corridor, and an air outlet through fan at the end of the corridor.

Temperature shows mainly longitudinal variations caused by the air flow dynamics from the air inlet to the forced outlet through the fan. Figure 1 shows the longitudinal variation of temperature in a forced ventilation room at 1 m above the slat. The highest temperatures occur in the central pens, whereas the lowest temperatures occur in the pens near the air inlets, at both sides of a central corridor, and in the pens near the air outlet, represented on the left and right sides of the figure, respectively. In pig rooms, controlling climate in the animal occupied zone becomes more important than controlling room climate [17]. Another frequently used distribution places the air outlet in a central exhaust chimney, such that a similar distribution of temperatures is obtained at both sides of the extraction fan, with higher temperatures near the air inlets from the central corridor. Such thermal gradients condition the airflows that transport pollutants, thus originating different concentrations depending on position. Moreover, the extraction capacity of the ventilation system is affected by the different densities of pollutants. For instance, CO_2 is heavier than air, unlike NH_3.

Relative humidity is also generally used as an indicator of air quality in livestock buildings, and proper humidity control is assumed to provide acceptable gas concentrations. Extreme high or low relative humidity is detrimental for livestock, workers and production buildings [18]. Under optimal ambient temperature conditions, variations in relative humidity in the range 50 to 75% do not affect animal welfare. Only values of relative humidity below 40% have detrimental effects on pigs, because such values cause drying of the mucosa, irritating cough and a reduction in feed intake. Relative humidity values above 80% have indirect effects insofar as such values intensify the effects of extreme temperatures [19].

As compared to temperature, the influence of humidity on growth rate is much lower. In fact, air humidity is not expected to have much influence on the performance of weaned piglets maintained within thermoneutrality [20]. Actually, incorporating relative humidity in climate control strategies on a swine farm had no impact on pig performance in cold weather [18]. However, high humidity levels can cause condensation on the animals and on the surfaces inside the building, which contributes to pathogenic organism growth and survival, and to building and equipment deterioration caused by internal surface condensation [21]. Moisture accumulated within the building structure can accelerate its corrosion and reduce the longevity of the building [22]. In fact, [23] identified wet surfaces as one of the main problems during middle-latitude cold periods inside livestock buildings and suggested that evaporation can be interpreted as a sink of sensible heat and a source of latent heat. Thus, when condensation forms on piglets, a part of their heat is used in water evaporation from the skin surface, which causes a heat loss from the animal that results in body cooling and increased disease susceptibility. Therefore, humidity is a key environmental variable, not only because of its direct effects on animal performance, but also because of its effects on the energy dynamics of the climate inside the building.

Concentration of Gases

Air quality inside livestock buildings is a key factor in achieving the optimal conditions for animal welfare, particularly under intensive production [24]. Actually, pork production is the second contributor of greenhouse gas emissions from the livestock sector [25]. Air quality is defined in terms of content of harmful gases such as ammonia (NH_3) and carbon dioxide (CO_2), organic dust and microorganisms. Incorporating control systems for CO_2 and NH_3 concentrations is feasible. Conversely, controlling organic dust and microorganisms is not feasible because of the difficulties in their long-term measurement.

Weaned piglet farms are among the swine farms with the highest levels of CO_2 concentrations because weaned piglets are very vulnerable to cold, and air exchange is intentionally reduced during the winter in order to maintain higher indoor temperatures [26]. The demanding temperature requirements of weaned piglets and the difficulty to combine them with the appropriate air quality and exchange require an efficient environmental control system that considers these restrictions to ensure animal welfare and improve farm productivity.

Total CO_2 production stems from three components: the breathing of animals, the quick decomposition of the urea found in urine and the decomposition of dry matter of slurry. Almost 90% of this CO_2 comes from breathing [27] and its production rate varies through the day, depending on animal activity [28-30]. The maximum recommended CO_2 concentration is 3000 ppm [10], such that when the levels remained above the recommended safe value, a negative effect on growth performance was observed [31]. In contrast, an epidemiologic study associated air quality with swine health on 28 swine farms in southern Sweden and established a maximum recommended CO_2 value of 1540 ppm [32]. Seasonal variations were observed in CO_2 concentrations inside the building, [26,33], where the highest values corresponded to cold seasons and the lowest values corresponded to warm seasons (Figure 2), which was directly related to the operation of the ventilation system [34]. Understanding the housing and management factors that affect CO_2 concentrations in pig buildings could improve the effectiveness of ventilation systems and, consequently, the indoor environment in pig buildings [33].

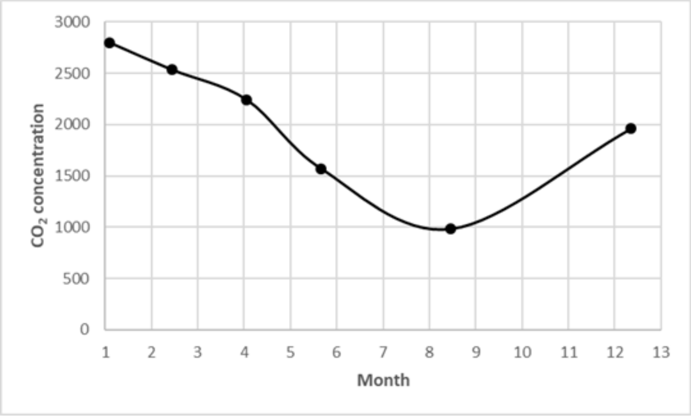

Figure 2: Average CO_2 concentrations in the animal zone for consecutive postweaning cycles along a year in a livestock building. Adapted from [34].

Ammonia (NH_3) release in livestock buildings originates from the nitrogen content in the urine and feces deposited in pits or on the building floor surfaces with or without bedding material [35]. Currently, NH_3 is one of the most critical pollutants for pig production [36,37] because of its direct relationship with the welfare and health of animals and workers [1,38]. Accordingly, many authors have analyzed the effects of NH_3 concentration on animal behavior, health, and productivity [39,40]. Generally, the negative effects of NH_3 concentrations on the physiological state of pigs in terms of growth and health have been acknowledged, but no consistent experimental results have been obtained. Actually, whereas some authors have claimed that high NH_3 concentrations have physiological effects on pigs [41,42], other authors have not found a clear influence on hepatic gene expression [39] or pig growth performance [42,43].

In accordance with [44], gas concentrations must be kept within limits that are not harmful to pigs through building insulation, ventilation, and heating. Yet, the directive does not establish any numerical limits [44]. Likewise, there is no consensus on the maximum allowable NH_3 levels. Whereas the International Commission of Agricultural and Biosystems Engineering recommended a maximum concentration of 20 ppm [11], other authors were more cautious, considering concentrations below 15 ppm as adequate [45]. They also recommended caution at levels between 15 and 25 ppm, and considered levels above 25 ppm as dangerous. More strict and safe exposure limits were proposed with values of 10 ppm [46] and 11 ppm [47].

From an environmental perspective, odor and NH_3 show a strong impact on animal production [37,48]. NH_3 emissions and deposition play a critical role in the acidification and eutrophication of ecosystems and contribute to indirect emissions of nitrous oxide [49]. For these reasons, NH_3 emissions are one of the concerns related to environmental control. Actually, most European countries have stressed the importance of reducing NH_3 and odor emissions in order to limit their negative impact on local communities and the environment [1].

NH_3 concentrations in swine buildings show large variations and are related to a number of factors, including animal age, activity and density, outdoor temperature, ventilation control, time of day or time of year [50-52]. The decrease in ventilation rates caused by the decrease in outdoor temperature has led to seasonal variations in NH_3 concentrations, with generally higher values in winter than in summer [50,53-55]. However, some authors have reported higher values in the summer period, stressing that the conditions that lead to an increase in NH_3 generation rates, such as building management, hygiene or volume, affect NH_3 concentrations more strongly than the factors that reduce concentration rates [56].

It has been demonstrated that pigs reared in clean environments with better air quality – with low ammonia levels – grow faster than pigs living in commercial farm buildings with sub-optimal air quality [33]. In fact, growth rate reductions in the range 0-30% were obtained in weaned pigs when exposed to 0 to 150 ppm NH_3 [57]. Similarly, growth was depressed along with feed intake when grower pigs were exposed to ammonia concentrations of 10 ppm [58]. In addition, a positive correlation between NH_3 concentrations and the increase in temperature was observed on most farms [59].

The daily evolution of NH_3 concentration showed a sinusoidal response for weaned piglets [60], which is in agreement with the results for odor and pollutant emission from finishing pigs [51]. NH_3 concentration in the animal-occupied zone varies with the temperature setpoint defined for the climate control system. At night, when air temperature is lower, the ventilation rate decreases, which causes an increase in NH_3 concentration. [50,52,60,61].

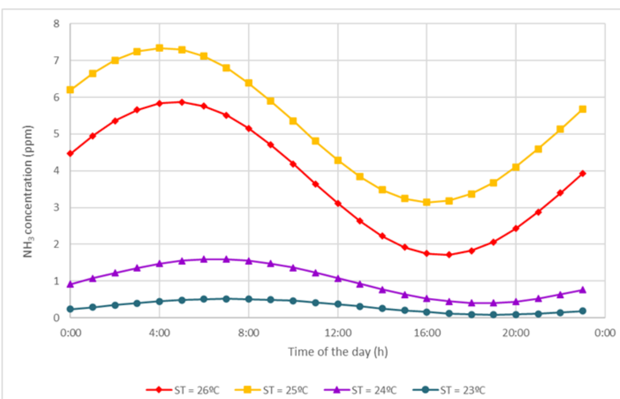

Figure 3: Sinusoidal NH_3 concentration daily pattern modeled by Fast Fourier Transform in postweaning livestock building for different environmental system setpoint temperatures (ST). Adapted from [60].

Animal Activity

The increasing concern of consumers over the welfare of farm animals raised for food, together with health and legal issues, led the Council of the European Union to enact directives laying minimum standards for the protection of the main farm species, such as pigs [44]. Animal welfare, food security and respect for the environment are the greatest challenges for livestock production in the near future. In this context, factors such as animal activity and behavior emerge as useful indicators for establishing a level of animal welfare on livestock farms, and become particularly relevant in intensive production systems, which restrict some behaviors considered as natural by ethology. As a result, producers are compelled to offer quality products, not only in terms of meat quality, but also in terms of the conditions of production, which must respect the environment and animal welfare.

In intensive production systems, ventilation rates depend mainly on CO_2 concentration and temperature [51], which are directly related to animal activity and vary on a daily basis [30]. Animal welfare has been defined by [62] as the avoidance of abuse and exploitation of animals by humans by maintaining appropriate standards of accommodation, feeding and general care, the prevention and treatment of disease and the assurance of freedom from harassment, and unnecessary discomfort and pain. According to this definition, many authors have related the changes in animal activity and behavior with a number of factors such as microclimate [63,64], environmental enrichment [65,66], health status [67], feed composition [68] or effect of weaning [69].

Typically, farmers assessed animal activity or behavior by visual inspection of the animals, but the increase in farm size and in the number of animals per farmer makes visual inspection economically unviable. For this reason, new technologies have been developed in the last few years that help farmers improve animal welfare. Activity level in groups of animals has been quantified by using non-disturbing methods such as passive infrared detectors (PID) [70-74], accelerometers [75-79], or radio-frequency identification systems [80,81]. More recently, some authors have proposed the use of machine vision systems for measuring activity in groups of animals and predicting water intake, among other variables [76,82-85]. The PID method, assessed against human observation of a group of weaned piglets [86], was more limited in terms of behavior detection but it was cheaper for farms and could be more widely implemented.

These methods can provide patterns of animal activity, which has been used as an indicator of animal health status [67]. Similarly, changes in water drinking patterns can reveal signs of subclinical diseases [87] or of increased competition in pens [88]. Therefore, measuring animal behavior can play a key role in the early detection of illnesses or other welfare problems and, consequently, in the mitigation of deficiencies in animal welfare and in the improvement of farm production efficiency [83]. In this regard, higher daily weight gains were obtained in production cycles of weaned piglets with less nighttime activity [89].

Weaning involves a challenge for piglets, which must face a negative energy balance, with low feed energy intake and high levels of activity, caused mainly by aggressive and exploratory behaviors [90]. Consequently, during the first days after weaning, piglets show high levels of activity that decrease rapidly. The frequency of aggression decreases over time from mixing [91], and the levels of feed intake increase in 2-3 days [92], which leads to the formation of a stable social hierarchy that allows for the stabilization of the levels of activity after the fifth day post-weaning [73]. Finally, during the last third of the cycle, activity gradually decreases until the minimum level of activity is reached at the end of the cycle, partly as a consequence of the reduction in the space to body mass ratio [73,91,93].

The daily pattern of activity has been represented by several authors using two sinusoidal models proposed by [11]: camel with two activity peaks [1,73,93,94] and dromedary with a single activity peak [72], as shown in Figure 4. Other authors have found both patterns in the daily behavior of pigs, depending on the ventilation system [94] or the age and weight of the animal [73]. Finally, a pattern resembling a rectangular function allowed to reduce the activity period, shortening the distance between activity peaks [95].

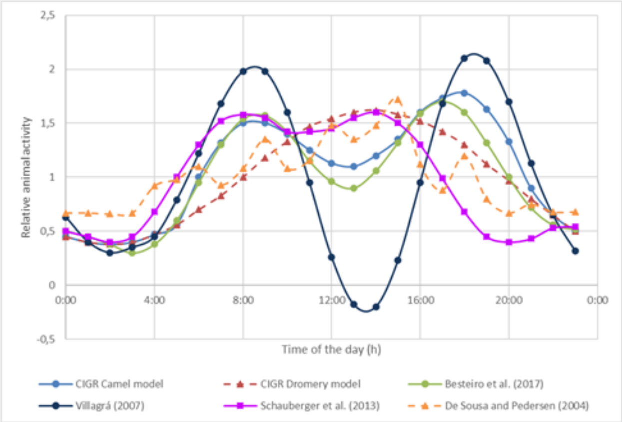

Figure 4: Daily patterns of animal activity. Adapted from [72] and [73].

Environmental Control Systems

The use of environmental control systems in livestock buildings is aimed at keeping a number of variables, such as temperature, humidity, and pollutant concentrations, at optimum levels because of their influence on many aspects of production, such as animal health and welfare [96-98]. Moreover, environmental control systems are the most efficient tools to ensure optimal production in livestock buildings [99, 100]. Some authors [100,101] have included environmental control systems under integrated control, a wider concept that combines many variables, including temperature, relative humidity or gas concentrations. Integrated control allows for decision-making and action-taking using available data and predictive models [102,103]. However, these variables are affected by a number of factors, such as the design and technical characteristics of the buildings and facilities [38], the herd size and growth stage of the animals [27,104], animal activity, feed type, and feed-dispensing system [105], or manure handling [106].

The control of facilities, commonly equipped with heating and ventilation systems to maintain the right indoor air quality and thermal environment [17], involves many problems.

First, the layout of swine farms is characterized by the presence of different types of facilities for the various phases of the production process. Some of these facilities, such as farrowing or postweaning facilities, require a large number of rooms and, consequently, a large number of measurement and control devices installed on a single farm. Even though modern controllers often use outside temperature and inside air quality as parameters to control ventilation settings, typically only one temperature probe is used to control these systems [17,107], and minimum ventilation rates are established to indirectly control the other relevant variables, such as gas concentrations or airborne dust. However, other variables of increasing interest because of their importance for swine production [108,109], such as humidity [97] or CO_2 and NH_3 concentrations [33,110] are not directly controlled [111].

Second, measuring these variables is difficult for three reasons: 1) some variables affecting animal welfare, mainly NH_3 concentrations, are very difficult or very expensive to measure on a continuous basis [33,112]; 2) the aggressive environment generated inside swine farms and the consequent intensive cleaning processes seriously affect the useful life of the sensors and actuators used; 3) the non-homogeneous environment inside the building makes it difficult to select the right location for the sensors or the moment and duration of the measurement and, therefore, to obtain significant measurements for the whole building and for animal health status [17,112].

Because temperature is the predominant control variable, the search for more effective methods of environmental control has led to the development of models for the prediction of temperature values inside pig buildings [23,101,113,114]. Most statistical models have focused on pollutant concentrations [115,116].

In addition, restrictions in the ventilation system can lead to an increase in heating energy consumption. Accordingly, incorporating humidity as a control variable could contribute to improving the environmental controls in these buildings [117] by reducing the high humidity levels that result in condensation and are detrimental to heating efficiency [17,23]. Recent research points to the incorporation of advanced estimation techniques into complex control systems to achieve energy savings [113,114,118-120], or to the use of a large number of sensors in advanced technologies in order to consider animal welfare [71,74,81,84,85,121]. Incorporating humidity as a control variable would involve higher ventilation rates, with positive consequences for animal welfare, a reduction in heating energy consumption and an improvement in productivity.

Currently, piglet commercial farms are incorporating environmental control systems with CO_2 concentration measurements. Daily variations of CO_2 production have been attributed to animal activity [27,122]. Actually, CO_2 concentrations showed some delay in relation to animal activity [73], while a more immediate response is shown due to the ventilation system [106].

Many authors [50,52,123] related the effect of setpoint temperature on NH_3 concentration with the influence of setpoint temperature on ventilation and, consequently, on NH_3 extraction from the building. NH_3 concentration patterns were strongly influenced by ventilation, which, in turn, was affected by setpoint temperatures. Sine wave equations provide a reliable pattern for real-time estimation of NH_3 concentration [51, 60] therefore can be implemented in many conventional controllers because of their simplicity.

Animal activity is related to animal behavior and welfare [124], temperature [13], humidity, and pollutant emissions to the atmosphere [71,95,122]. In this respect, a number of daily activity patterns for pigs are available from the literature [73,94,95]. The evidence available for such relationships points to the need to develop climate control systems based on the animals and their behavior under different building environmental conditions [125].

Because of the complexity of environmental control systems and the presence of non-linear relations between some environmental variables in livestock buildings [101,116], data-driven methods of artificial intelligence capable of modeling non-linear processes can be useful. Among these, some common methods are artificial neural networks (ANN) [126,127], hybrid models that combine ANN and wavelet transform (WT) [128], adaptive neuro fuzzy inference system (ANFIS) [120], autoregressive integrated moving average (ARIMA) [113,114] and computational fluid dynamics (CFD) [119].

Developing prediction models that help understand the evolution of environmental variables can be highly useful in the development of new environmental control algorithms [101,129,130]. These models can be used to build more effective environmental control systems that are capable of anticipating events and show a better response, which can improve energy savings and animal welfare.

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