Technological innovation in the ambience of facilities for farm animals: Applications

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ABSTRACT

The chapter discusses the progress of science and technology in facilities for farm animals. It is noteworthy that technological innovations often surpass science's ability to assimilate them quickly, especially with the exponential growth of databases. The text contextualizes the evolution of animal facilities throughout history. In the past, the focus was on physical elements and equipment to control the microclimate, but with technological advancements, the introduction of artificial intelligence (AI) has revolutionized the way these environments are planned and managed. AI enables real-time data collection, analysis, and interpretation, making it possible to make precise adjustments to environmental conditions to meet the needs of animals. Technology has evolved to record animal activities that may be related to health, including movements, behaviors, and vital signs. Despite the advances, the text points out structural and biological challenges that may hinder the implementation of new technologies in facilities. However, the importance of facility planning to ensure animal welfare and productivity is highlighted, especially when considering thermal comfort. This involves understanding the specific needs of animals in relation to the environment, choosing suitable building materials, and adopting sustainable practices such as renewable energy systems. In short, the chapter emphasizes that the revolution in the ambience of animal facilities, driven by artificial intelligence, represents a significant advance in the search for adaptable and optimal conditions, creating a healthier and more efficient environment for animal production.

Keywords: Shelter, Ambience, Thermal comfort, Heat stress, Building materials.

1 INTRODUCTION

The history of science often shows that new tools advance faster than the science that adopts them. With the exponential growth of data scales and volumes, new questions will arise and require more advanced scientific models. It is imperative to empower the next generation of scientists to explore and conduct research in this expanded information environment (BENSON et al., 2010).

In the setting of facilities for farm animals, evolution reflects a continuous development throughout history. In the past, considerations of animal welfare and environmental conditions have focused on physical elements, such as orientation, ceiling height and lanterns in houses, the type of roof tile used, or the implementation of equipment, such as fans and sprinklers, to manipulate the microclimate of the rearing environment.

However, with technological advancements, especially in the contemporary era, the approach to ensuring optimal conditions for animals has evolved significantly. The introduction and integration of artificial intelligence (AI) has revolutionized the way these environments are designed and managed. AI makes it possible to collect, analyze, and interpret a massive amount of data in real-time, allowing for precise and dynamic adjustments to environmental conditions to meet the specific needs of animals.

This transformation allowed for an unprecedented level of customization and adaptation of the facility, taking into account not only basic factors but also complex variables such as animal behavior patterns, social interactions, optimal light levels, temperature, humidity, and air quality.

It is known that inadequate microclimatic conditions can impact the health of animals. In agriculture and livestock, technological advances are mainly aimed at assisting in the assessment of the health of these organisms. In the case of farm animals, the stress caused by hot climates can generate susceptibility to diseases, and thus affect feed intake, weight gain, reproduction and production of milk, meat, and eggs. According to Brust et al. (2017), technology has evolved to record animal activities that may or may not be related to health standards. For Kumar and Hancke (2014), an example of these variables include head movement; rumination, locomotion, and food and water intake activity (ZEHNER et al., 2012), core body temperature, and heart rate (KULDHARAN et al., 2023).

In general, technological advances have supported the observation of animal behavior, which is a complex process. Not only must it be able to identify the individual in its environment, but also interpret patterns of movement, e.g., agonistic or sociable. Traditional behavioral research requires hours of training to accurately identify animal behavior based on detailed ethograms. Similarly, extensive artificial intelligence training with lots of images is required to "recognize" distinct behaviors. However, this technology offers the advantage of allowing continuous monitoring for longer periods, eliminating the need for human observers, resulting in large-scale and more cost-effective data collection (VALLETTA et al., 2017).

Overall, AI offers the ability to predict and respond quickly to changes in environmental conditions, thus promoting the possibility of providing for the welfare and performance of farm animals. This revolution in the environment of animal facilities, driven by artificial intelligence, represents a significant advance in the search for optimal and adaptable conditions, providing a healthier and more efficient environment for animal husbandry and production.

Despite this technological revolution, there are still structural problems in the environments where animals are kept, or even biological ones that fluctuate influenced by multiple factors. In this condition, there is the difficulty or impossibility of implementing new technologies. Planning facilities for farm animals is a critical step in ensuring an environment conducive to the welfare and productivity of these animals.

In order to plan facilities that promote thermal comfort, it is essential to understand the specific needs of animals in relation to the environment. Dairy cattle, for example, are sensitive to sudden changes in temperature and, therefore, it is necessary to consider an ideal temperature range, as well as strategies to mitigate the effects of excessive heat or intense cold. The response of these animals to heat stress is immediate and can be measured in milk production.

The choice of building materials also plays a crucial role in the thermal control of animal facilities. Materials with insulating properties are selected to ensure efficiency in heat retention or dissipation as required. To assist in the thermal control of the environment, strategically placed ventilation systems are essential to regulate temperature and humidity within the facility. Adjustable windows, targeted vents and exhaust systems are incorporated to ensure a constant and controlled airflow, keeping the environment airy and comfortable. According to Bardi (2018), software that provides scientific information on construction materials related to animal welfare, which are easy to access and use, should be adopted. They should be seen as a library on the specific topic to help people who have some difficulty accessing physical and virtual libraries.

In addition to this scenario, the design of structures, such as roofs, walls and floors, is planned to maximize thermal comfort. Reflective surfaces for roofs and walls can reduce heat absorption, while the orientation of buildings can optimize natural ventilation by allowing for adequate airflow. Structures that offer adequate shading are designed to protect animals from direct sun exposure while providing cool and comfortable areas.

Generally speaking, facility planning for the thermal comfort of animals should not only address immediate needs but also consider sustainable practices. This includes the adoption of renewable energy systems, such as solar panels to power ventilation or cooling systems, as well as the rational use of water and its treatment.

2 BUILDING MATERIALS TO AID AMBIENCE IN ANIMAL FACILITIES

Building materials play an important role in creating environments that provide thermal comfort to animals. According to Miragliotta et al. (2006), within poultry facilities, the microclimate is influenced by a variety of factors, including orientation, location, type and size of the building, as well as the construction materials used, with special emphasis on the roofing material. In addition to these structural aspects, the animals themselves, management practices, and equipment adopted for thermal control play significant roles.

Next, some concepts and practical applications of these materials will be addressed, with the reflections on the results of the animal's performance, in addition to their influences on the thermal control of the environment.

For the thermal insulation of the facility, different materials help to keep the internal temperature stable, reducing thermal stress on the animals and contributing to their well-being and productivity. Insulating materials, such as glass wool, expanded polyurethane, or polystyrene foam, are often used to minimize heat transfer. They are applied to walls, roofs, and floors to keep the indoor temperature more stable, reducing heat loss in winter and excessive gain in summer.

According to Castro (2012), understanding the concepts of heat exchange mechanisms requires consideration of thermal conductivity (λ). This parameter represents the amount of heat that a material transmits in a given temperature difference, either from the inside to the outside or vice versa. It is an indicator of the material's efficiency in absorbing or emitting heat. For Ferreira (2005), the determination of the thermal conductivity of a material requires the consideration of the thermal resistance (R), which is intrinsically linked to the thickness of the material. This dimension determines the material's ability to restrict or facilitate heat transfer. Therefore, as the thickness increases, so does the resistance to heat transmission.

According to Tinôco (2001), thermal insulation consists of materials with low thermal conductivity, combined to achieve efficiency in the conduction of heat in the systems. In fibre composite insulation, the solid material is finely dispersed in air-filled space. In these systems, the effective thermal conductivity depends not only on the radiative properties of the solid material, but also on the nature and volumetric fraction of the air or void space. An important parameter is the density (mass/total volume), which is influenced by the bonding of the solid material. When small voids or hollows are formed by the fusion or adhesion of part of the solid material, a rigid matrix is established. If these spaces are isolated from each other, the system is known as cell isolation. Examples of these rigid insulations include foams, especially those composed of plastic or glassy materials such as polyurethanes, eucatex, and glass wool.

In a study conducted by Arruda (2018) on a commercial layer farm, the thermal performance of sheds with and without thermal insulation on the roof of the house was evaluated. It was found that the uninsulated house reached considerably higher temperatures in all 4 rows of cages evaluated and, in the 3 heights, reaching a peak of 35.32°C (without insulation/height 1 – closer to the ground), compared to 30.08°C (with insulation/height 1 – closer to the ground). This represented a significant difference of 5.24°C between treatments. The presence of thermal insulation under the roof clearly demonstrated its efficiency in the thermal control of the sheds. The author pointed out that the insulator hinders heat dissipation, preventing the internal temperature of the sheds from matching the external temperature, due to its properties of high thermal resistance and low thermal conductivity. However, even with the isolation, the recorded values were still above the thermoneutrality of the birds. In view of this, the study suggested the need to implement other cooling and ventilation measures in commercial houses to ensure optimal conditions for birds.

Another type of material used in the installation that interferes with the indoor microclimate is the *roof covering.* According to Nããs et al. (2001), roofs and roofing materials play a key role in the radiation thermal load in poultry facilities. Specifically, the roof is a significant component, directly influencing the incidence of the thermal radiation load on the animals.

The materials used in the construction of the roof, when they have high reflectance on the outside, play a crucial role in reducing solar energy absorption and heat gains. These materials play a decisive component in establishing the environmental thermal comfort of the facilities (CASTRO, 2012). Sevegnani et al. (1994) concluded that, in relation to thermal comfort, clay tiles provide the best performance, followed by aluminum and thermal tiles. In third place are simple asbestos cement tiles, followed by zinc tiles, and finally fiberglass tiles.

The use of reflective surfaces has been a practice employed as a thermal insulator due to its low emissivity and absorptivity characteristics, as well as high reflectivity in the infrared spectrum (MICHELS et al., 2008). A study evaluated the effects of the combination of reflective paint (white latex paint applied to asbestos-cement tiles) and artificial ventilation on broiler production. The results obtained showed a reduction in the values of radiant heat load, black globe humidity index and temperature-humidity index in the environment, indicating the benefits of this combination for the thermal conditions in the poultry housing (PASSINI et al., 2013).

The roof of the aviary must have a high reflective capacity and thermal insulation against the sun's rays. These characteristics help to limit the penetration of solar radiation into the material, preventing excessive heating of the aviary at high temperatures (ROCHA et al., 2008).

In view of the study by Araújo (2011), with the objective of evaluating the effect of the management of cover and artificial ventilation on thermal comfort indices and performance of broiler birds, it was found that the joint application of white paint on the roof and artificial ventilation proved to be effective in improving the thermal comfort of the analyzed environment. In isolation, the use of paint or artificial ventilation alone has not been shown to be effective.

According to the same authors, simple environmental modifications, such as reflective painting or the use of artificial ventilation, contribute to increased weight gain and feed consumption by poultry. A positive effect is observed when reflective paint and artificial ventilation are combined, resulting in better comfort indices and favoring the performance of the animals.

The use of green roofs in animal production is a sustainable option that seeks to mitigate the impacts of agro-industrial systems on global climate change and mitigate the effects of global warming on production environments. Since part of the air pollutants, including greenhouse gases, originate in animal production facilities, green roofs can play a role in the absorption of CO2, contributing to the natural cycle of this gas and improving the environmental balance (SOUSA; BARBOSA, 2023).

In a survey conducted to evaluate facilities used in raising young buffalo, it considered two distinct types of roof covering, including a conventional roof and another equipped with polypropylene mesh. In the study, the physiological responses of buffaloes to heat stress in hot and humid conditions in Thailand were observed. The results indicated that buffaloes housed under the modified roof had lower heat stress compared to those under a standard roof. This modification has been shown to be effective in reducing the heat load from the radiation on the roof, representing an effective means of relieving heat stress in young buffalo (KHONGDEE et al., 2013).

As for the construction of walls, materials such as bricks, concrete or thermal insulation panels are used. These materials can be chosen for their ability to retain heat in the winter and keep the environment cool in the summer. According to Roriz (2013), the thermal behavior of a structure refers to its response to different temperatures and thermal variations. This response is influenced by essential architectural variables, such as solar orientation, surface finish, ventilation openings, as well as the characteristics of materials and construction methods, aspects highlighted in this work. The variables related to materials and construction methods are defined by specific thermal properties, such as thermal capacity, thermal transmittance and solar factor.

As for flooring, in poultry farming, studies investigating the effect of the type of flooring in broiler housing have highlighted the benefits of separating animals from bedding to improve animal welfare. Research such as that of Cengiz et al. (2013) identified that the use of perforated floors can reduce the occurrence of problems such as leg dermatitis, hock burns, and plumage contamination, compared to deep bedding systems, as observed by Almeida et al. (2017). In addition, studies, such as the one conducted by Chuppava et al. (2018), have shown significant economic advantages in the use of perforated floors, associated with an increase in production performance.

In addition to the building materials, the structure of the facility includes controlled ventilation systems. Adjustable windows, strategic openings, and exhaust systems are essential for regulating airflow, keeping the room ventilated and controlling temperature. The air coming in and out of a *freestall* house for dairy cows is very important for keeping the indoor environment healthy. This air, under natural conditions, can be controlled by the curtains on the sides of the installation (SHEN; ZHANG; BJERG, 2012).

If the ventilation rate is sufficient, the indoor environment becomes dry and cool. If the natural air from outside the house is used correctly, it is possible to adjust the internal environment precisely, and also save energy and reduce pollution (concentration of gases and dust). To have adequate air in this type of environment, it is necessary to use the curtains intelligently, according to the amount of air, the direction of the wind and the temperature inside and outside the house (SHEN; ZHANG; BJERG, 2013).

In poultry farming, evaporative cooling is the primary strategy used by producers to cope with elevated temperatures. This system operates by cooling the outside air as it passes through a set of evaporative panels. These panels, often composed of cellulose, are designed to remain constantly moistened. When air circulates through them, the evaporation of the water droplets present on their surface promotes the reduction of the temperature of the surrounding air. *Pad Cooling* is the evaporative cooling system commonly used in poultry houses (CONSTANTINO, 2018).

Dark House *houses* were developed for chickens and are based on the variation of light in the environment, adjusted according to the age of the birds and their well-being. One of the notable points of this system refers to the programmed method of ventilation (ABREU; ABREU, 2011). While in the conventional poultry farming system fans are employed to promote welfare, in the *Dark House* an exhaust fan is used. This exhaust fan performs essential functions, such as air exchange to regulate temperature and the removal of ammonia from the house (AMARAL et al., 2011).

In conventional sheds for the production of poultry and dairy cattle, as well as pigs, it is common to find a structure called lantern. As mentioned by Abreu and Abreu (2000), experiments have shown that the air flow through the lantern is directly associated with its opening area, the height difference between the air inlet and outlet openings, the dimensions of the air inlet openings and the temperature difference between the internal and external environment.

According to Vilela et al. (2020), in industrial poultry production, one of the crucial points to ensure a comfortable environment for the birds and, thus, good responses in the zootechnical indexes, is the correct choice and sizing of the ventilation system installed in the breeding houses.

In the context of natural ventilation, generated by the air intake openings and the presence of the lantern, according to Camargos (2020), it is evident that this results in a reduction of up to 9.2°C in the internal temperature of the shed. This device becomes essential in buildings that have internal heat sources, since these sources tend to intensify the chimney effect and accentuate the natural exhaustion of the internal air through the lantern. It is notable that sheds with larger air outlet areas have a better thermal performance, reducing the internal temperature by up to 5.1°C.

Generally speaking, in poultry farming, mechanical ventilation is commonly performed in two distinct ways: 1) by negative pressure or exhaust, exhaust fans remove the indoor air from the premises, creating a partial vacuum that stimulates the entry of fresh air. This air travels throughout the house, and the maintenance of negative pressure is essential to ensure the adequate intake of air, in terms of direction and speed, to mix with the air already present in the environment (OBERREUTER; HOFF, 2000; FRAME; ANDERSON, 2002); 2) By positive pressure or pressurization, which can be transverse or longitudinal, it uses fans to blow the outside air into the house, forcing the internal air out. When the curtains remain closed, this system is called tunnel-type ventilation, and its efficiency is directly linked to the good sealing of the aviary (BAÊTA; SOUZA, 2010; FERREIRA, 2016).

The microclimate of the farm animal facilities is influenced by the materials used in the flooring. Materials such as concrete, rubber or special mats not only provide comfort for animals, but also contribute to the thermal stability of the environment. In addition, the substrates used in the beds of the rest area are included in these "floor materials", since they have an impact on the thermal load that comes into contact with the animals.

In some housing systems there is no need or require a minimum amount of bedding, however, intensive confinement systems for dairy or pig production depend on the adequate availability of bedding materials in the animals' resting areas to ensure the welfare and hygiene of these animals. The primary role of bedding is to provide a resting surface that is thermally comfortable and pleasant for the animals, since studies such as the one by Wolfe et al. (2018) have shown that cows spend more time lying down when the stalls have a soft, dry surface.

Compost barns *for dairy cows* have stood out among dairy animal facilities, attracting considerable interest from both dairy farmers and the scientific community. These sheds, which adopt composted bedding, have been widely studied as an alternative system for housing dairy cattle. The concept involves an open, covered resting area, lined with lignocellulosic material, where compost is actively stirred to aerate (oxygenate) and maintain an active composting process.

Generally, the structures of these sheds have a retaining wall that surrounds the bed, separating the feeding aisle from the compost (bedding). The bedding material most commonly used in the composting process includes sawdust or dry shavings, kept dry to ensure dryness of the bed surface and moisture absorption. A detailed analysis of the thermal, chemical, and physical properties of these bedding materials is of great environmental and economic importance, assisting dairy farmers in the proper management of these systems. A study conducted by Damaceno et al. (2022) revealed a linear relationship between thermal conductivity, moisture content, and bulk density, while thermal resistivity showed a reduction proportional to the increase in particle size.

Regarding the shade cover on the external structures of the facility, such as awnings or extended roofs, they provide shade and protection from extreme weather conditions, helping to maintain a more comfortable temperature in the grazing or resting areas. For Souza et al. (2010), reducing heat stress in animals is possible through artificial shading strategies, which can be implemented using a variety of materials, such as polypropylene screens, eucalyptus pillars, straw, fiber cement, galvanized and iron tiles.

Shade plays a crucial role in reducing heat stress in livestock by offering a microclimate that relieves heat load, as highlighted by Edwards-Callaway et al. (2021). Its fundamental purpose is to provide a favorable environment to meet the welfare needs of animals. Although heat stress has been widely studied and addressed in dairy production systems, the investigation of this issue in the beef cattle supply chain is less comprehensive. Beef animals, like any other, are susceptible to heat stress during periods of high temperatures if they can't dissipate heat properly.

As described by Binns et al. (2002), shade offers direct relief from solar radiation. However, even in shaded areas, animals can be affected by shortwave reflected radiation, such as that coming from the heated ground, although this influence is considerably reduced in the shade. Shade can be natural, provided by trees or structures, or artificial, using metal tiles, clay or meshes for shading. Its effectiveness varies depending on the operation, management method, and geographic location.

When designing animal facilities, it is crucial to consider several shade-related variables, such as the thermal properties of the materials used, the ground cover under shade (e.g., areas covered by vegetation that prevent the ground from overheating and are less reflective), the height and size of the shade structure, the amount of shade per animal, orientation and ventilation, among other factors, as mentioned by Owen et al. (1994).

For example, when planning the installation of fixed individual pens for dairy calves, it is recommended to consider an area of 1.50 to 1.80 m² per animal. In case the calves are kept in individual houses in the pasture, it is essential to maintain a minimum distance of 2 m between each of them, providing a total area of 2.2 to 3.0 m² per calf. This provision aims to ensure adequate natural ventilation, allowing air renewal and the elimination of gases generated by the accumulation of animal feces and urine, such as carbon monoxide, methane, ammonia and hydrogen sulfide. In addition, the adequate incidence of sun rays within the facilities contributes significantly to the reduction of humidity in the environment, providing better salubrity of the environment. To achieve this goal, it is crucial to position the calf in such a way that it captures sunlight in the morning, offers protection from winds, and ensures that the land is well drained to avoid soil waterlogging (DE OLIVEIRA et al., 2005; GOMES; MADUREIRA, 2016).

Choosing the right building materials for dairy cow or calf breeding facilities can bring a great differential in thermal comfort, ensuring a more stable and healthy environment for animals in all seasons of the year. The study carried out by Campos et al. (2005) revealed that in regions with severe summers, where the average temperature reaches 31ºC, the use of shade (50% shade mesh and open on all sides) as a shading option for the animals became unfeasible. This is due to the Globe Temperature and Humidity Index (ITGU) reaching 87.44, significantly exceeding the limit established as a stress index of 84.00. In view of this scenario, the same authors recommend the adoption of individual shelters, such as the 'Casinha Tropical' model, either open or closed on the sides, with UTI values very close to the limit, with 84.03 and 84.54, respectively.

Generally speaking, studies conducted by different researchers highlight the beneficial effects of shading for cattle in various conditions. Mitlöhner et al. (2001) found that cattle housed under polypropylene fabric with 80% solar filtration, positioned at a height of 3 meters, had a lower respiration rate, higher feed intake and weight gain, reaching final weight 20 days before animals without access to shade. Blaine and Nsahlai (2011), in South Africa, during the winter, provided 2.87 m² of shade per head with corrugated iron sheets at a height of 5 meters. They observed that shaded cattle had higher final weight, better weight gain, feed conversion and carcass weight difference, as well as less panting and longer rest time, compared to animals without access to shade.

In Australia, Angus cattle received 3.3 m² of shade per animal, with black polypropylene fabric with 80% solar filtration at 4 meters high, as found by Gaughan et al. (2010). These researchers observed a reduction in body temperature and wheezing, as well as an increase in growth rate, weight gain, finishing weight, and warm carcass weight. Sullivan et al. (2011) investigated different shade areas (0, 2.0, 3.3 and 4.7 m²/animal) using black solar fabric with 70% solar filtering at 4 meters height. They concluded that shading improved animal welfare and performance, and shade areas greater than 2.0 m² showed improvements in cattle welfare.

In tropical climates, Castro-Peréz et al. (2020) observed that the increase in shade space in feedlots linearly increased daily gain and dry matter intake, most notably between 1.2 and 2.4 m² of shade per head. Other studies have indicated that adult animals can benefit from 7 m² of shade per animal (GASQUE, 2008). A minimum height of 4 meters for shade is recommended in order to avoid interference with the airflow inside the corral. To keep the floor dry, strategies include leaving 15 cm spaces unshaded in the structure (LAGOS et al., 2014).

2.1 TO ASSESS HOW INSULATING BUILDING MATERIALS ARE TO PROVIDE THERMAL COMFORT TO ANIMALS, WHAT ASSESSMENT METHODS EXIST TO BE APPLIED FOR THIS PURPOSE?

There are several ways to evaluate the ability of building materials to provide thermal comfort for animals. Some of the most commonly used valuation methods include:

Coefficient of Thermal Conductivity (λ): This coefficient indicates the ability of the material to conduct heat. The lower the λ value, the better the thermal insulation of the material. Specialized laboratories can perform tests to determine this coefficient.

R-Value: is a measure that represents the thermal resistance of a material. The higher the R-Value, the better the thermal insulation. This value is often used for insulation in walls, roofs, and floors.

Laboratory Tests: Specialized laboratories can conduct specific tests to evaluate the thermal performance of materials. Tests of thermal conductivity, resistance to heat flow, and behavior in different simulated climatic conditions are some examples.

Computer Simulations: Computer models use simulation software to predict the thermal behavior of materials and structures under different weather conditions. This can be useful in the planning and *design* phase of facilities to determine the expected thermal performance. Computational Fluid Dynamics (CFD) modeling emerges as a powerful tool for analyzing the thermal environmental conditions in facilities for dairy cows, such as the compost barn, as well as for poultry and pigs. This method provides the opportunity to improve projects and management practices in this type of structure.

Computational fluid dynamics is an advanced tool capable of simulating a variety of phenomena, including heat and mass transfer, phase shifts, chemical reactions, and more. This enables the study of computational models of physical systems under different conditions of interest. There are a variety of CFD codes and software available to meet fluid dynamics modeling needs, applicable to various areas of study.

In the context of animal facility modeling, it is crucial that these codes enable the modeling of flow-dependent properties, including flow in porous media. In addition, they should allow the user to implement specific functions of interest and be able to generate varied meshes, adapting to the particularities of each study (CHEN et al., 2021). The authors conducted research to investigate alternative ventilation schemes of a cage-free aviary to provide practical designs for a comfortable indoor environment at the level of chickens. According to the results of the study, they concluded that computational modeling of fluid dynamics was a powerful tool that made it easier for researchers to address animal welfare issues in animal housing projects.

In the processes of adopting construction materials, it is very common to follow Standards and Certifications. There are specific standards and certifications for building materials that guarantee their thermal performance. For example, certificates such as LEED (Leadership in Energy and Environmental Design) or energy efficiency seals can be presented for materials that meet certain thermal insulation criteria. In the case of civil engineering in Brazil, for the construction of buildings for human beings, there are the following regulations in force, which deal with the thermal performance and/or energy efficiency of buildings, included in NBR 15.220/ Thermal performance of buildings (ABNT, 2005) and NBR 15.575/ Residential buildings - Performance (ABNT, 2013).

By considering the evaluation methods, producers or professionals responsible for the construction of the facilities can choose the most appropriate materials to provide adequate thermal comfort to the production animals, thus ensuring the well-being and production efficiency.

3 TECHNOLOGIES TO ENSURE THERMAL COMFORT IN LIVESTOCK FACILITIES

The use of technologies allows the creation of controlled environments, ensuring optimal thermal comfort for production animals, reducing heat stress and promoting conditions conducive to their well-being and productive performance.

The search for innovative and efficient technologies to ensure thermal comfort in livestock facilities has been key to promoting animal welfare and optimizing productivity. Several technologies are employed for this purpose:

3.1 SMART VENTILATION SYSTEMS

Technological developments in the ventilation of animal production environments include innovative methods such as sensor-controlled ventilation. This approach uses temperature and humidity sensors to automatically adjust ventilation according to weather conditions, ensuring a more stable and comfortable environment for the animals. Additionally, targeted ventilation systems are employed to manage airflow strategically, promoting uniform circulation and preventing heat buildup in specific areas or times.

The prediction of ventilation in cattle sheds has been approached through computational fluid dynamics (CFD) simulation, a widely used technique to estimate the ventilation rate (TOMASELLO et al., 2019; FAGUNDES et al., 2020; PAKARI; GHANI, 2021). The DFC makes it possible to assess how factors, such as wind direction and speed, as well as the size of vents, influence this rate (YI et al., 2020). However, DFC is limited to the simulation of specific situations, not in real time, as each scenario requires time to converge, depending on the available computational capacity. This time interval restricts its immediate application in ventilation forecasting, especially when wind conditions are variable.

In addition, the accuracy of DFC is strongly influenced by the technician's expertise in both the theory and use of the software. Alternatively, statistical methods have been employed to develop predictive models of ventilation in houses. These statistical models are often based on the correlation between environmental measures, such as wind conditions and vent sizes, and ventilation rates. For example, response surface methodology (RSM) and neural network models are common approaches to this prediction (SHEN; ZHANG; BJERG, 2012; AYATA; ARCAKLIOĞLU; YILDIZ, 2007; FERREIRA; WOULD; RUANO, 2002).

Machine learning, due to its ability to model from large data sets, in various areas of research, without the need for prior knowledge of the relationship between inputs and outputs, becomes a useful tool for production systems (BECKER et al., 2021). Several machine learning algorithms have been tested to predict the relationship between indoor environmental conditions and animal behavior (ARULMOZHI et al., 2021; LIU et al., 2014).

3.2 AUTOMATED MONITORING AND CONTROL:

Automation systems: Using automated monitoring technologies to control temperature, humidity, and ventilation, adjusting them according to the needs of the animals and weather conditions in real time.

The sensors used to aid in the investigation of the thermal comfort of animals are those strategically placed to measure the body temperature of the animals, allowing precise adjustments in the environmental control systems. According to Halachmi et al. (2019), wearable technologies with sensors currently dominate the market in the area of precision livestock farming. Most of the applications on these farms focus on monitoring tags attached to the animals (marks on the neck, legs, or ears) or inserted into the animal's body (bolus). These applications are widely used in large animals such as dairy cows, beef cattle and horses, given the economic rationale for investing in individual monitoring tags, as well as the availability of multiple areas to position sensors. According to the authors, the trend for the near future is that a single sensor, such as a camera or robot, can meet multiple monitoring needs in a large number of animals.

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