

## Passive Cooling Strategies Towards the Sustainability of Livestock Building - An Overview

Parag Acharya<sup>1\*</sup>, Amit Sharma<sup>2</sup>, Yashwant Singh<sup>3</sup>, and Rajneesh Sirohi<sup>4</sup>

Livestock Production Management, Regional Research & Technology Transfer Station (RRTTS), Bhawanipatna, Odisha University of Agriculture & Technology, Odisha

(Received : August, 2022 185/22 Accepted : February, 2024)

### Abstract

India, being a tropical country, faces a significant challenge in the livestock sector due to heat stress during the summer months. Heat stress in livestock induces various physiological, biochemical, behavioral, and adaptive changes, leading to severe reproductive and economic losses. Addressing this issue is crucial for sustainable production and economic returns in the livestock industry. The key to mitigating heat stress lies in effective housing management and ensuring a comfortable micro-environment for the animals. While active cooling systems, relying on conventional energy sources, have been traditionally employed, their economic viability and environmental impact raise concerns. As an alternative, passive cooling methods are gaining attention for their potential to enhance sustainability in livestock building designs.

**Key words :** Heat stress, livestock, micro-climate, sustainability, passive cooling

India is a tropical country with hot dry to hot humid climate. During summer, mean daily temperature ranges from 30-35 °C and frequent-

ly reaches upto 45 °C in harsh summers in north and north-west regions of the country with a diurnal temperature variation of more than 15 °C (Attari and Tyagi, 2008). Marquis *et al.* (2007) reported that inter - governmental panel on climate change predicted a temperature rise between 1.1 to 6.4 °C by the end of 21st century. Severe heat stress challenge productive, reproductive performance of animals, affect normal behavior and create severe health problems and even lead to death of animals (Jordan, 2003; Tao and Dahl, 2013). The optimum temperature, humidity and THI index for better performance of cross bred cattle are 19-26 °C , 52- 66 % and 65- 68 in subtropical region like India (Mote *et al.*, 2014). High temperature coupled with high humidity compromise animal performance (Marai *et al.*, 2009). High yielding animals are more susceptible to heat stress (Singh and Upadhyay, 2009). Arise in temperature of 2- 4°C will decrease milk production by more than 15 million tons by 2050 in comparison to current trends of milk production (India's National communication to the United Nations Framework Convention on Climate Change).

Heat stress is a major challenge for livestock production in India and likely to be more serious in future with current trends of global warming. For this reason, to decrease the adverse effect of heat stress on animals and to maintain the production level, livestock housing along with the cooling systems and design techniques are very much required. The objective of housing is to safeguard animal health and welfare of animals. Consequently, animal

\*Corresponding author : Email : paragacharya17@gmail.com

<sup>1</sup>Scientist, Livestock Production Management, Regional Research & Technology Transfer Station (RRTTS), Bhawanipatna, Odisha University of Agriculture & Technology, Odisha

<sup>2</sup>Associate Professor, Department of Livestock Production and Management, College of Veterinary Science, RampuraPhul, GADVASU, Punjab, India

<sup>3</sup>Professor, Department of Livestock Farm Complex, College of Veterinary Science, RampuraPhul, GADVASU, Punjab

<sup>4</sup>Assistant Professor, Department of Livestock Production and Management, DUVASU, Mathura, UP.

performance will be improved. Cooling systems used in livestock building could be active or passive. In active cooling system, conventional energy is the main energy source. The different mechanical cooling strategies *viz.* fan pad, fan fogger, cooler have been effectively used to modify micro climate in animal sheds. Conventional cooling systems require very high initial investment which is not feasible for most of the resource less poor farmers of our country. There is inadequate and interrupted power supply occurs in peak summer season. Moreover, energy sector produces highest 47 % annual global greenhouse gas emission which is a global environmental concern (IPCC, 2014). In short, active cooling/ mechanical cooling system are not economically viable and have negative effects on the environment. So, these are the bottlenecks of installing active cooling/ mechanical cooling systems in Indian scenario (Kamal, 2012). Therefore, as an alternative method, passive cooling methods are being examined towards the sustainability of livestock building designs. Passive cooling involves natural processes and techniques that reduce heat gain and remove internal heat with minimal or no reliance on conventional energy sources. This paper reviews existing passive cooling systems implemented in livestock buildings and explores recent advances in heat stress management.

With this back drop the manuscript aims at reviewing the content in two parts i.e. (i) passive cooling techniques those are already adopted in livestock building and (ii) passive cooling systems need to be adopted in animal building in the changing scenario. The review is structured as follows.

### Passive cooling techniques already adopted in livestock building

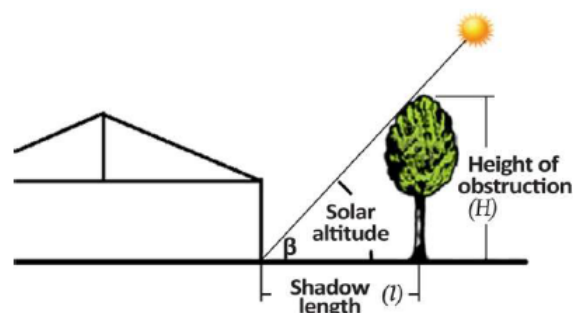
#### Shade, Height and Orientation for dairy cows:

Shed is one of the easiest and effective means to reduce heat load on animals in hot climate (Vanlaer *et al.*, 2014). Sheds help to decrease radiant heat load of animals by 30 percent (Bond *et al.*, 1993). Sheds of squared shaped structures absorb higher amount of heat (Ahachad *et al.*, 2005). 'A' shaped shed roof has advantage over flat roof in hot climate because it casts its

shadow on other half and saves that part from direct solar radiation.

Shed height of less than 3.0 m. affects ventilation, which ultimately reduces convective heat loss from animals. Similarly, shed with too much height is not desirable also; rather it's a financial burden for the farmer. The impedance of the sun and sky radiation at 2.2 m and 3.5 m are 64 % and 61 % respectively (Pandey *et al.*, 2008).

Local climate along with prevailing wind direction mostly decide orientation of animal shed. A farmstead must get maximum sun exposure in the north while minimum in the south. The long axis of a shed should be in the E-W direction to get a cooler environment (Kelly *et al.*, 1950). Trees act as wind breaks and many trees around the site, particularly in the eastern and southern sites protect the farmstead from prevailing strong wind. The minimum distance between the building and the windbreaks, to avoid shading, is given by: (Walker *et al.*, 1974).



$$l = H \times \cot \beta \text{ where,}$$

$l$  = shadow length

$H$  = height of obstruction (windbreak)

$\beta$  = solar altitude

#### Roof

The roof should be light, strong, durable, weather proof, a bad conductor of heat and free from tendency to condense moisture inside. There are several materials available as roofing material. It may be hay or straw, tiles, slates, corrugated asbestos, aluminum sheets, galvanized steel, plywood and different types of plastic material. Hay thatch is more useful in hot dry climate than hot humid climate. A 4-6 inch thick hay

thatch is adequate to prevent heat conduction from the upper surface. It has been measured that direct solar radiation energy flow per hour on animal body is 340 kcal/m<sup>2</sup> (Thomas *et al.*, 2012). Providing shed is an easy and efficient way to mitigate the effects of heat stress on pasture in hot climates (Vanlaer *et al.*, 2014). Housing design and the material used for the roof play an important role in the microclimate modification and reduction of radiant heat load inside the shed (Badino, 2007). Type of roofing material determines pitch of roof, which should be 35° for thatched roof; 25° to 30° for tile roof; 12° to 18° for sheet roof, and it should not exceed 45° for any roof material (Thomas *et al.*, 2012).

Wood makes good shed material and is most comfortable roof. But cracks develop in it with time and liable to fire risk. Asbestos sheet are more effective as top layer in double roof shelter. Colour of the roof also influences the cooling of a livestock building. The heat stress of the animals reduces significantly with the replacement of dark coloured roofs with brighter coloured roofs. Roofs of animal houses can also be modified in various ways to reduce heat load and to provide more comfort to animals housed inside it.

Polythene shade cloth or agro-net is placed over asbestos roof of animal houses for a better microclimate and to prevent heat stress during summer days. Khongdee *et al.* (2010) reported that shade cloth roofing offered a more efficient way to minimize heat stress than that of normal roof. Kamal *et al.* (2014) observed that crossbred calves in agro-net shed in open paddock performed better than asbestos sheet shed.

Mud plaster over asbestos sheet prevents excessive heating of asbestos roof during peak summer. Soil, cow dung and wheat straw are mixed in different proportion for making of mud plaster and then it is spread over asbestos sheet (Gautam *et al.*, 2020). Narwaria *et al.* (2017) reported that modified thatch (2 inches thick thatch panels made by bamboo structures and mud bitumen plastered on it provided the coolest microenvironment during the summer season as compared to ordinary thatch.

In another method, installing sprinklers on roof top, spreading jute bags soaked with water on top surface of roof were employed to lower roof temperature during hot days. Efficiency of metal roof can be improved by sprinkling water over it. Water soaked jute bags that are put on roof tops in hot and arid weather lowers roof temperature by as much as 15°C (Sanjay and Prabha Chand, 2008).

A green roof is a layer of vegetation planted over the top of a flat. Different kinds of plants as part of the building enclosure have been shown to enrich its thermal performance. Due to their capacity to intercept solar radiation, plants provide effective shade but, due to evapotranspiration, they also have an air-cooling effect (Jaffal *et al.*, 2012). Both roofs and walls can be provided with vegetation to reduce heat stress in animal buildings. In accordance with Taleb (2014), a green roof is structured with various layers, encompassing drainage and root barrier elements, along with water channels. Castleton *et al.* (2010) indicate that the customary supplementary load linked with an extensive green roof is approximately 120–150 kg/m<sup>2</sup>. Primarily employed in residential structures due to their proven ability to diminish heating and cooling expenses, green roofs hold promise for potential application in animal housing in the distant future. This adaptation for animal environments, however, remains a prospective avenue for exploration.

#### **Thermal insulation/False ceiling**

Insulation prevents heat flow and it's required to reduce energy consumption. Roof insulation is most important than wall insulation or floor insulation. One study reported that, cows feel more comfort and give more milk inside a shed with false ceiling along with manual and mechanical cooling (Das *et al.*, 2015). Insulation material like mineral wool, cellulose, cork, polyurethane (PUR), expanded polystyrene (EPS), extruded polystyrene (XPS), etc. were used in human dwellings previously. New concept of advanced insulation materials includes vacuum insulation materials (VIMs), gas insulation materials (GIMS), nano insulation materials (NIMs) and dynamic insulation materials (DIMs) etc. (Jelle *et al.*, 2010). They

are one of the best high performance low conductivity thermal solution for the insulation purpose. Vacuum insulation panels (VIPs) have thermal conductivities ranging from 3-4 Mw/(Mk), lower than traditional thermal insulation materials like polystyrene products (Jelle *et al.*, 2010). Use of aerogel, represent a modern day solution like use of carbon black to suppress radiative transfer and with low thermal conductivity (Ramkrishnan *et al.*, 2008). These above mentioned insulation materials might be used in modern livestock housing if they become cost effective and suitable to animal shed.

### Floor Cooling (Conductive cooling systems)

In conductive cooling, direct contact is established between a lying down animal and a cooled surface (water mattress, or any other heat exchanger embedded under the bedding). This is more suited to humid conditions. It allows heat exchange from the body of the animal to the cooled surface. Conductive cooling requires less energy than evaporative cooling units. It helps in improving animal hygiene and reduces humidity in the barn compared to evaporative cooling systems.

Ortiz *et al.* (2015) conducted a study to investigate the effectiveness of heat exchangers buried 25 cm below the surface of cow beds using either sand or dried manure as bedding materials. The researchers justified the use of deep bedding to protect the heat exchanger and ensure the comfort of the cows. The water in the heat exchanger was cooled to 70°C, and the study observed that sand outperformed dried manure as a bedding material. While, there was no significant difference in the respiration rate between cooled and non-cooled cows, the core-body temperature exhibited a decrease of 0.13°C when sand was used and 0.14°C when dried manure was employed as bedding. Additionally, the study reported low values of conductive heat flux, with 28.63 W/m<sup>2</sup> observed when sand was used as bedding compared to 7.35 W/m<sup>2</sup> when dried manure was utilized (Ortiz *et al.*, 2015). These findings suggest that sand is a more effective bedding material for the conductive cooling system, leading to a greater reduction in core-body temperature and higher conductive heat flux compared to dried manure.

In a comprehensive study, Perano *et al.* (2018) investigated the efficacy of conductive cooling in mitigating heat stress among dairy cows. The experiments subjected dairy cows to hot and humid conditions, with half of the cows being subjected to conductive cooling through cooled water mattresses. The circulating water in the mattresses was maintained at temperatures of 4.5°C or 10°C. Cows exposed to 4.5°C water temperature exhibited an increase in milk production by up to 11% compared to the control group, which experienced the same environmental conditions without cooling.

A cooler contact surface gives more comfort to pigs during hot days. Shi *et al.* (2006) conducted a study, where a group of pigs provided with a floor cooling system and another group was kept without these facilities. In floor cooling system water pipe lines were spread under the concrete floor. It was observed that when mercury increased from 23 to 34°C, 60 % of the pigs those were provided with floor cooling area spent their time lying. On the contrary, the case was different in the control group. 57 % of the pigs were lying comfortably when the temperature rose to 30°C and situation was tougher between 30-33°C. Only 10-20 % of the pigs were seen lying on the sleeping area. The situation was precarious when the ambient temperature increased to 33°C. At 33°C, no pigs were observed in this area; instead the animals were lying or standing in the play area where access to water was provided.

In the study conducted by Bull *et al.* (1997), it was observed that gilts exhibited a preference for conductive cool-pads over drip-cooling or snout-cooling methods, suggesting a heightened efficacy in reducing heat load through conductive cooling mechanisms. Silva *et al.* (2006) conducted an experiment focusing on the behavior, production performances, and physiological parameters of lactating sows. The experimental setup involved individual pens equipped with plates circulating water at 17 °C, housing the pigs in the experimental group, while the control group sows were maintained in conventional pens. The results demonstrated notable improvements in the treatment group compared to the control group. In terms of perfor-

mance metrics, the treatment group exhibited higher feed intake (6.47 kg/day) in contrast to the control group (5.60 kg/day). Additionally, the treatment group displayed superior milk production (10.20 kg/sow/day) compared to the control group (8.05 kg/sow/day). Furthermore, the weight of piglets at weaning was significantly higher in the treatment group (6.42 kg) than in the control group (5.30 kg).

Behavioral aspects of lactating sows were also positively influenced by the cooled floor system. Sows in the treatment group spent more time nursing and less time sleeping, indicating an enhanced maternal engagement. Moreover, lactating sows subjected to cooling demonstrated higher feeding and drinking rates, potentially contributing to the improved production outcomes observed. Physiological parameters further supported the benefits of the cooled floor system. Sows in the treatment group exhibited lower rectal temperatures and respiratory rates compared to their uncooled counterparts, suggesting a more favorable thermal environment. Additionally, the cooled sows displayed a reduced frequency of urination, indicative of potential stress alleviation and improved comfort.

In conclusion, the findings of this study underscore the positive impact of a cooled floor system on the behavioral, production, and physiological aspects of lactating sows. The preference for conductive cool-pads by gilts, as noted by Bull *et al.* (1997), aligns with the broader efficacy of passive cooling methods in improving overall welfare and performance in livestock. These observations contribute valuable insights to the ongoing exploration of practical and sustainable cooling solutions in animal husbandry.

### Evaporative Cooling

Evaporative cooling is the process by which water droplets are evaporated into air to cool the ambient air temperature. By doing this, heat of ambient air is absorbed and water vapors are imparted into air. It results in lowering the air temperature up to a saturation point but increase in relative humidity. It could be either direct or indirect evaporative Cooling.

Wang *et al.* (2008) conducted a study on

20-year's weather data from nine representative cities with various climates in China to find the suitability of an evaporative pad cooling system in poultry houses. He observed that by using the evaporative pad cooling system, the average air temperature inside poultry houses could be reduced below 28 °C for over 65% of the days in one hot season for Beijing, Xi'an and Jinan, while the temperature of about 70% of the days could be lowered to below 30 °C for the remaining cities.

In hot and dry conditions the efficiency of evaporative pad cooling systems can reach over 80% (Timmons and Baughman, 1984; Kittas *et al.*, 2003). Cruz *et al.* (2006) found that, in southwest of Portugal during summer season, air temperature inside broiler buildings could be reduced from 39 °C to 27 °C by an evaporative pad cooling system.

Average evaporative cooling efficiency ranged from 69.2% on July 18, to 72.0% on August 3 in the Mediterranean region of Turkey. Dagtekin (2009) conducted a study in a typical poultry house, to know the effect of evaporative pad cooling systems and found that the temperature decrease in pad exit during the experiment was between 7.3 °C and 4.4 °C. Samer *et al.* (2015) carried out an experiment with an objective to enhance the efficiency of evaporative cooling pads by using desiccant materials. It was applied before and after the pads. The treated air will be able to absorb more moisture from the cooling pads if desiccant material absorbs air moisture before entering the air into the pads. It was the hypothesis. The results showed that the desiccant materials are suitable to absorb moisture from air in dynamic motion. The adsorption capacity depends on the starting conditions (temperature, relative humidity, ventilation rate) and attains its half value after 150 min, and then the desiccant material should be reactivated.

In a study, pregnant sows were kept in rooms with natural ventilation (openings in side walls) or in rooms equipped with mechanical ventilation (fogging system). But, during the lactation phase, the females were kept in three types of rooms - naturally ventilated, mechanically ventilated or zone ventilated—with an associated evaporative pad system. Cooled

air was pumped to the area above the sows' head through a PVC tube in the third method. Considering the suitable room for lactating sows, it was found that the evaporative-cooled air stream had a significant impact on reduction of respiratory rate in females compared to sows kept in the naturally ventilated room or in the room with mechanical ventilation (50 vs. 54 and 57 breaths per minute, respectively). However, when piglet weaning weight was taken into study, it was found that, it is best to keep sows in a naturally ventilated room during pregnancy, and then in rooms with zone cooling supported by an evaporative-cooling pad system (Romanini *et al.*, 2008)

An evaporative-cooling pads system assists in decreasing the air-stream temperature in zone-cooling technology (Justino *et al.*, 2014; Perin *et al.*, 2016; Romanini *et al.*, 2008; Watanabe *et al.*, 2019). Justino *et al.* (2014) used air of velocity above 3 m/s, cooled by an evaporative-pad system, distributed around group of lactating sows (through plastic ducts with holes in it). This indirect cooling method had a significant impact on respiratory rate reduction (62.5 vs. 46.6 breaths per minute); a decrease in surface-skin temperature (34.7 °C vs. 34.3 °C) and thus it also significantly improved the sows' sensible heat loss. Watanabe *et al.* (2019) carried out another experiment in which he compared physiological parameters of sows at first, second and third parturition. The females were kept in a building with natural ventilation alone (cross-ventilated, open side-wall building) or additionally exposed to a cooling system (front part of the animal body subjected to air stream of 10 m/s, additionally supported by evaporative pads). There was an increase of daily ration intake in gilts (36.1 vs. 28.2 g) and in all the tested groups a lower skin-surface temperature (e.g., in gilts 32.9 °C vs. 34.8 °C) and lower respiratory rate (e.g., in gilts 54 vs. 80 breaths per minute) were found.

Chib *et al.* (2015) conducted study in poultry farm, college of veterinary science, GADVASU, Ludhiana on efficacy of passive cooling vis-à-vis mechanical fan-pad cooling system to alleviate heat stress and improving growth performance of broilers. Cooling treat-

ments comprised of Tc (control without any cooling system), TJSC passive cooling (jute sheet roof shading and curtains with gravity flow sprinklers), TGSC passive cooling (green sheet roof shadings and curtains with gravity flow sprinklers) and TFP (fan pad mechanical cooling systems). The results of shed microclimate indicated that maximum ambient temperature, temperature humidity index (THI) and duration and level of heat stress in control were significantly ( $p \leq 0.05$ ) higher than passive (TJSC and TGSC) and mechanical (TFP) cooling group. Growth performance and feed efficiency, in both passive (TJSC and TGSC) and mechanical cooling (TFP) were significantly ( $p \leq 0.05$ ) better than control. However, growth performance and feed efficiency of chicks was significantly ( $p \leq 0.05$ ) higher in TFP than chicks in passive (TJSC and TGSC) cooling groups. In passive cooling systems (TJSC and TGSC), the plasma catalase, glutathione peroxidase (GPx) and BUN were significantly ( $p \leq 0.05$ ) lower than control (Tc) but significantly higher than mechanical cooling (TFP) system. The stress related behavioral activities, panting, preening, scratching and wing flapping were significantly ( $p \leq 0.05$ ) higher in control than in cooling system. It was concluded that passive cooling system can be an environment friendly and energy independent alternate to intensive mechanical cooling system to reduce heat stress and improve growth and welfare in broiler production.

#### **Passive cooling systems need to be adopted in animal building**

#### **Earth integrated buildings**

The basic principle of earth integrated building is that in warm climate the ground temperature is much lower than the ambient air temperature and that temperature remains almost constant with slight change throughout the year. This temperature gradient between outside and inside is sufficient enough to keep the animal shed cool, thus reduces stress on animals. These kinds of buildings are most suitable in hot areas provided windows and skylights are there for proper ventilation. (Martzopoulou *et al.*, 2020). These earth integrated buildings are economically viable and support the sustainability of

livestock buildings.

### **Passive cooling roof in hot arid areas**

A passive cooling roof was designed for livestock building in Algeria to observe the cooling effect on animals (Cheikh *et al.*, 2008). The innovative design featured a stratified arrangement, consisting of a layer of rocks immersed in water, positioned between a metal plate ceiling and an aluminum plate. An essential component of this configuration was the introduction of an air gap between the water layer and the aluminum plate. Furthermore, the aluminum plate was treated with a white titanium-based pigment to enhance its solar reflectance, thereby maximizing the cooling effect. This particular roofing model proved to be particularly well-suited for livestock buildings with horizontal arch or span roofs. The experimental results demonstrated a significant reduction in the internal temperature of the shed, with a notable decrease of 6-10°C compared to conventional livestock buildings. This achievement highlights the effectiveness of the passive cooling roof in creating a more comfortable and thermally regulated environment for the animals.

### **Earth to air heat exchangers (EAHE) with wind tower**

In arid and hot climates, wind tower is built along with earth to air heat exchangers for enhancing passive cooling. A wind tower is made up of specific material and consists of inlets one facing windward and exit facing leeward directions. The outside air passes through the inlet opening due to pressure difference and continues to circulate through the buried pipes of the EAHE, keeping the indoor environment cool.

Differing from earth to air heat exchanger (EAHE) concept, some workers (Krommweh *et al.*, 2014; Rosmann *et al.*, 2010; Buscher *et al.*, 2007; Van Caenegem 2007, 2008) have designed another housing system which is based on modular housing concept and integrates a geothermal heat exchanger (GHE). Here, no tubes are laid in the soil like the previous EAHE. Instead, the building has slurry pits and walls which are prefabricated. The construction elements are highly insulated and are constructed on strip foundations. Air is

passed through the cavity between the soil and the slurry pit. Then, supply air is led through a central corridor into the under-roof area and from there into the animal sections or directly from the GHE cavity to the animal area (Van Caenegem 2007, 2008). GHE system has high potential to save energy and resources.

### **Ground Channel Ventilation (GCV)**

Innovative in its approach, ground channel ventilation (GCV) is a recent ventilation design that utilizes subterranean air supply channels to deliver fresh air directly to the animal occupied zone (AOZ) through slatted floor inlets, employing displacement airflow. Despite gaining traction in commercial applications, there is a scarcity of comprehensive studies characterizing the distribution of indoor air and the functionality of underground air supply channels within GCV designs. (Arcidiacono *et al.*, 2018)

In a study conducted by Jeppsson and Botermans in 2014, the focus was on the analysis of dust and ammonia releases in indoor breeding environments. The investigation considered three distinct combinations of negative pressure ventilation systems integrated with ground-coupled ventilation (GCV). The three ventilation systems studied were as follows: A) High exhaust ventilation with air inlets in the ceiling (Conventional system), B) High exhaust ventilation with incoming air close to the AOZ through ground channels, and C) Combined high (75% of max ventilation rate) and low exhaust (25% of max ventilation rate) ventilation with incoming air close to the AOZ through ground channels. The findings of the study revealed noteworthy differences in the concentrations of ammonia in the workers' breathing zone compared to ventilation system A, while ventilation system C exhibited the lowest ammonia concentration in the workers' breathing zone.

Ventilation System A, characterized by high exhaust ventilation with air inlets in the ceiling (Conventional system), represented a baseline scenario. Ventilation System B, employing high exhaust ventilation with incoming air in proximity to the AOZ through ground channels, exhibited an increased concentration of ammonia in the workers' breathing zone

compared to System A. In contrast, Ventilation System C, which involved a combined approach of high and low exhaust ventilation rates with incoming air close to the AOZ through ground channels, demonstrated the lowest concentration of ammonia in the workers' breathing zone. This indicates that the integration of high and low exhaust ventilation rates, coupled with the use of ground channels for incoming air, contributed to a more favorable indoor air quality, particularly in terms of reduced ammonia levels in the breathing zone of workers. These scientific insights contribute valuable information for optimizing ventilation strategies in indoor breeding facilities to ensure both animal welfare and worker health.

### Conclusion

Livestock buildings play a crucial role in facilitating optimal growth conditions for animals, maintaining a thermal environment within the boundaries of their thermo-neutral zone. Heat stress in animals significantly diminishes their productivity, affecting key factors such as milk production, weight gain, and fertility. This review article delineates two primary categories of passive cooling systems and design techniques tailored for livestock buildings. The first category focuses on specific systems, such as conventional shade structures designed for dairy cows. The discussion delves into critical aspects like the height, orientation, insulation, roofing materials, and natural ventilation parameters associated with these shading structures. The second category encompasses urban systems that are adaptable to livestock buildings. Examples include earth-integrated buildings, passive cooling roofs, earth-to-air heat exchangers integrated with wind towers, and ground channel ventilation within livestock housing. By integrating elements like earth integration and harnessing wind and ground channels, these techniques aim to naturally regulate the internal temperature of livestock facilities, aligning with principles of environmental sustainability. In conclusion, this review underscores the critical role of passive cooling systems and design techniques in ensuring the sustainable development of livestock buildings. The proposed adoption and adaptation of these

passive cooling strategies hold the potential to positively impact the overall well-being and productivity of livestock, thereby fostering sustainable practices in the livestock industry.

### References

- Ahachad, M., Belarbi, R., Draoui, A., and Allard, F. (2005) Passive cooling for the development of the aviculture sector in the North of Morocco. In *12èmes Journées Internationales de Thermique*. 431-436.
- Arcidiacono, C. (2018) Engineered solutions for animal heat stress abatement in livestock buildings. *Agricultural Engineering International: CIGR Journal*.
- Attri, S. D., and Tyagi, A. (2008) Climate profile of India. *Indian meteorological department of Earth Sciences*. New Delhi.
- Badino, F. (2007). Helping cows to regulate body heat. *Informative Agarino Supplemento*, **62(39)**:18-21. DOI: 10.5958/2277-940X.2017.00124.3
- Bond, T. E., Kelly, C. F., Morrison, S. R., and Pereira, N. (1967) Solar, atmospheric, and terrestrial radiation received by shaded and unshaded animals. *Transactions of the ASAE*, **10** (5), 622-6625. (doi: 10.13031/2013.39745) @1967
- Bull, R.P., Harrison, P.C., Riskowski, G.L., and Gonyou, H.W. (1997) Preference among cooling systems by gilts under heat stress. *J. Anim. Sci.*, (**75**): 2078–2083. <https://doi.org/10.2527/1997.7582078x>
- Buscher, W., Nannen C., and Schneider T. (2007) Thermo-technical characteristics of a modular stable. *Landtechnik*, **62(5)**: 340-341.
- Castleton, H.F., Stovin, V., Beck, S.B.M., and Davison, J.B. (2010) Green roofs: building energy savings and the potential for retrofit. *Energy Build.*, **42(10)**:1582-1591. <https://doi.org/10.1016/j.enbuild.2010.05.004>
- Cheikh, H. B., and Bouchair, A. (2008) Experimental studies of a passive cooling roof in hot arid areas. *The Open Fuels & Energy Science Journal*, **1(1)**. <http://dx.doi.org/10.2174/1876973X00801010001>
- Chib, S. (2015). 'Studies on passive cooling strategies for summer stress management in broiler production'
- Cruz, V.F., M. Perissinotto, and E. Lucas. (2006) Cooling livestock buildings by pad and fan evaporative cooling systems (pad cooling). In: *Animal housing in hot climates: a multidisciplinary view*. Naas I.A. Ed., Campinas, Brazil: 37-38. [https://www.researchgate.net/publication/233853720\\_Animal\\_Housing\\_in\\_Hot\\_Climates\\_A\\_multidisciplinary\\_view](https://www.researchgate.net/publication/233853720_Animal_Housing_in_Hot_Climates_A_multidisciplinary_view)
- Dağtekin, M., Karaca, C., and Yıldız, Y. (2009). Performance Characteristics of a Pad Evaporative Cooling System in a Broiler House in a Mediterranean Climate. *Biosyst. Eng.*, **103**: 100-104. <http://dx.doi.org/10.1016/j.biosystemseng.2009.02.011>

- Das, S.K., Karunakaran, M., Barbudde, S.B. and Singh, N.P. (2015) Effect of orientation, ventilation, floor space allowance and cooling arrangement on milk yield and microclimate of dairy shed in Goa. *J. Anim. Res.*, **5**(2): 231-235. <http://dx.doi.org/10.5958/2277-940X.2015.00040.6>
- Gautam, V. N., Shrivastava, S., Lakhani, G. P., and Tripathi, K. N. (2020) Emendation of performance in dairy animals using modified roof: A review. *Journal of Entomology and Zoology Studies.*, **8**(3): 1007-1011. <http://www.entomoljournal.com/>
- Intergovernmental Panel on Climate Change (IPCC); Pachauri, R.K., and Meyer, L. *Climate Change 2014: Synthesis Report*; IPCC: Geneva, Switzerland, 2015. [Google Scholar]
- Jaffal, I., Ouldboukhite, S.E., and Belabi, R. (2012) A comprehensive study of the impact of green roofs on building energy performance. *Renew. Energy.***43**: 157-164. <https://doi.org/10.1016/j.renene.2011.12.004>
- Jelle, B.P., Gustavsen, A., Baetens, R., and Grynning, S. Nano (2010) Insulation Materials Applied in the Buildings of Tomorrow. *Concrete ideas for Passive Houses.*, **35**. <http://www.dti.dk/inspiration/26870>
- Jeppsson, K. H., and Botermans, J. (2014) Dust levels depending on ventilation system in buildings for growing finishing pigs. In *Proceedings international conference of agricultural engineering, 6–10 July 2014, Zurich, Switzerland (pp. 1-6)*. European society for agricultural engineers. <http://www.eurageng.eu/>
- Jordan, E.R. (2003) Effects of heat stress on reproduction. *J. Dairy Sci.*, **86**: 104–114. [https://doi.org/10.3168/jds.S0022-0302\(03\)74043-0](https://doi.org/10.3168/jds.S0022-0302(03)74043-0)
- Justino, E., Nääs, I.D.A., Carvalho, T.M., Neves, D.P., and Salgado, D.D.A. (2014) The impact of evaporative cooling on the thermoregulation and sensible heat loss of sows during farrowing. *Eng. Agric.* **34**: 1050–1061. <https://doi.org/10.1590/S0100-69162014000600003>
- Kamal, M. A. (2012) An overview of passive cooling techniques in buildings: design concepts and architectural interventions. *Acta Technica Napocensis: Civil Engineering & Architecture.* **55**(1): 84-97. <http://constructii.utcluj.ro/ActaCivilEng>
- Kamal, R., Dutt, T., Patel, B.H.M., Dey, A., Chandran, P.C., Barari, S. K., Chakrabarti, A. and Bhusan, B. (2014) Effect of shade materials on microclimate of crossbred calves during summer. *Vet. World.*, **7**(10): 776-783. <http://www.veterinaryworld.org/>
- Kelly, C. F., Bond, T. E., and Ittner, N. R. (1950) Thermal design livestock sheds. *Agric. Engg.*, **36**: 173- 80.
- Khongdee, S., Sripoon, S., Chousawai, S., Hinch, G., Chaiyabutr, N., Markvichit, K. and Vajrabukka, C. (2010) The effect of modified roofing on the milk yield and reproductive performance of heat-stressed dairy cows under hot-humid conditions. *Anim. Sci. J.*, **81**(5): 606-611. <https://doi.org/10.1111/j.1740-0929.2010.00771.x>
- Kittas, C., T. Bartzanas, and A. Jaffrin. (2003). Temperature gradients in a partially shaded large greenhouse equipped with evaporative cooling pads. *Biosystems Engineering.***85**(1): 87-94. [https://doi.org/10.1016/S1537-5110\(03\)00018-7](https://doi.org/10.1016/S1537-5110(03)00018-7)
- Krommweh, M.S., P. Rosmann, W. Buscher. (2014) Investigation of heating and cooling potential of a modular system for fattening pigs with integrated geothermal heat exchanger. *Biosystems Engineering.***121**: 118-129. <https://doi.org/10.1016/j.biosystemseng.2014.02.008>
- Marai, I.F.M., El-Darawany, A.A., Abou-Fandoud, E.I. and Abdel-Hafez, M.A.M. (2009) Reproductive and physiological traits of Egyptian Suffolk rams as affected by selenium dietary supplementation during the sub-tropical environment of Egypt. *Livest. Res. Rural Dev.*, **21**: 10.
- Marquis, M., Averyt, K. B., Tignor, M., and Miller, H. L. (2007) IPCC Climate change: Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University press, United Kingdom and New York, USA.
- Martopoulou, A., Firfiris, V., and Kotsopoulos, T. (2020). Application of urban passive cooling systems and design techniques in livestock buildings. In *IOP Conference Series: Earth and Environmental Science.*, **410** (1): 012029. IOP Publishing. DOI 10.1088/1755-1315/410/1/012029
- Mote, S.S., Chauhan, D.S. and Ghosh, N. (2014). Effect of environmental factors on lactation yield and lactation length of Holdeo crossbred cattle. *Indian J. Appl. Res.*, **4**(10).
- Narwaria, U. S., Singh, M., Verma, K. K., and Bharti, P. K. (2017). Amelioration of thermal stress using modified roof in dairy animals under tropics: A Review. *Journal of Animal Research.*, **7**(5), 801-812. <http://dx.doi.org/10.5958/2277-940X.2017.00124.3>
- Ortiz, X. A., Smith, J. F., Rojano, F., Choi, C. Y., Bruer, J., Steele, T., Schuring, N., Allen, J., and Collier, R. J. (2015). Evaluation of conductive cooling of lactating dairy cows under controlled environmental conditions *J. of Dairy Science.*, **98**(3): 1759-1771. <https://doi.org/10.3168/jds.2014-8583>
- Ozgener, L. (2011) A review on the experimental and analytical analysis of earth to air heat exchanger (EAHE) systems in Turkey. *Renewable and Sustainable Energy Reviews.*, **15**(9): 4483-4490. <https://doi.org/10.1016/j.rser.2011.07.103>
- Pandey, V. (2008) Management of heat stress in dairy cattle and buffaloes for optimum productivity. *Journal of Agrometeorology (Special issue-Part 2.)*, 365-368. [https://www.researchgate.net/publication/278330701\\_Management\\_of\\_heat\\_stress\\_in\\_dairy\\_cattle\\_and\\_buffaloes\\_for\\_optimum\\_productivity?enrichId=rgreq-53a207a6d670731729bc44b06999d568-XXX&enrichSource=Y292ZXJQYWdI0zi3ODMzMDcwMTtBUzoy](https://www.researchgate.net/publication/278330701_Management_of_heat_stress_in_dairy_cattle_and_buffaloes_for_optimum_productivity?enrichId=rgreq-53a207a6d670731729bc44b06999d568-XXX&enrichSource=Y292ZXJQYWdI0zi3ODMzMDcwMTtBUzoy)

- NDA4NDk1NzZmODAwOTZAMTQzNDQzNDQyMTc-0MQ%3D%3D&el=1\_x\_2&\_esc=publicationCoverPdf
- Perano, K. M., Shelford, T. J., and Gebremedhin, K. G. (2018) Experimental Analysis of Condensation Rate in Conductive Cooling Systems for Dairy Cattle. *Applied Engineering in Agriculture.*, **34**(2), 425-436. (doi: 10.13031/aea.12259) @2018
- Perin, J., Gaggini, T.S., Manica, S., Magnabosco, D., Bernardi, M.L., Wentz, I., Bortolozzo, F.P. (2016) Evaporative snout cooling system on the performance of lactating sows and their litters in a subtropical region. *Ciência Rural.*, **46**: 342-347. <https://doi.org/10.1590/0103-8478cr20141693>
- Ramakrishnan, K., Krishnan, A., Shankar, V., Srivastava, I., Singh, A., & Radha, R. (2008) Modern aerogels. *Date last accessed*, 27.
- Romanini, C.E.B., Tolon, Y.B., Nääs, I.D.A., de Moura, D.J. (2008) Physiological and productive responses of environmental control on housed sows. *Sci. Agric.*, **65**: 335-339. <https://doi.org/10.1590/S0103-90162008000400002>
- Rosmann, P., H. Boge., and W. Buscher. (2011) Rating of an air-to-air tube-type heat exchanger in a piglet house. *Landtechnik*.**66**(5): 345-348.
- Samer, M., Abdelsalam, E., and Elhay, Y. A. B. (2015) Enhancing the efficiency of evaporative cooling pads for livestock barns and greenhouses by moisture adsorption. *Agricultural Engineering International: CIGR Journal.*, **17**(4): 36-63.
- Sanjay, M. and Prabha, Chand. (2008). Passive cooling techniques of buildings: past and present-a review. *ARISER*. **4**(1): 37- 46.
- Shi, Z.; Li, B.; Zhang, X.; Wang, C.; Zhou, D.; Zhang, G. (2006). Using floor cooling as an approach to improve the thermal environment in the sleeping area in an open pig house. *Biosyst. Eng.***93**: 359-364. <https://doi.org/10.1016/j.biosystemseng.2005.12.012>
- Silva, B. A. N., Oliveira, R. F. M., Donzele, J. L., Fernandes, H. C., Abreu, M. L. T., Noblet, J., and Nunes, C. G. V. (2006) Effect of floor cooling on performance of lactating sows during summer. *Livestock Science*, **105**(1-3): 176-184. <https://doi.org/10.1016/j.livsci.2006.06.007>
- Singh, S.V., and Upadhyay, R.C. 2009. Impact of temperature rise on physiological function, thermal balance and milk production of lactating Karan fries and Sahiwal cows. *Indian Vet. J.*, **86**(2): 141-144.
- Taleb, H. (2014). Monitoring energy reduction through applying green roofs to residential buildings in Dubai. *International Journal of Sustainable Design*, **2**(3), 229-243. <https://doi.org/10.1504/IJSDDES.2014.065041>
- Tao, S. and Dahl, G.E. (2013) Invited review: heat stress effects during late gestation on dry cows and their calves. *J. Dairy Sci.* **96**: 4079-4093. <https://doi.org/10.3168/jds.2012-6278>
- Thomas, C.K., Sastry, N.S.R., and Ravikiran, G. (2012) Dairy Bovine Production. 2nd revised edition, Kalyani Publisher, Ludhiana, pp. 125. <http://dx.doi.org/10.5958/2277-940X.2017.00124.3>
- Timmons, M.B., and G.R. Baughman. (1984) A plenum concept applied to evaporative pad cooling for broiler housing. *Trans. ASAE*, **27**(6): 1877-1881. (doi: 10.13031/2013.33061) @1984
- Van Caenegem, L. (2007). Supply air from the cavity below the housing. ART-Berichtenr. 672/2007 (12 p.). Tanikon, CH-8356 Etttenhausen, Switzerland (in German).
- Van Caenegem, L. (2008). Energy efficiency in farrowing houses using geothermal energy. KTBL-Schrift 463 Energy-efficient agriculture: 162-172 (in German).
- Vanlaer, E., Moons, C.P.H., Sonck, B. and Tuytens, F.A.M. (2014) Importance of outdoor shelter for cattle in temperate climates. *Livest. Sci.*, **159**: 87-101.
- Walker, J. N., and Duncan, G. A. (1974) Greenhouse location and orientation AEN-32 (Kentucky: University of KY, Dept. of Agric. Eng, Agriculture Engineering Extension Publications)
- Wang, C., Cao, W., Li, B., Shi, Z., and Geng, A. (2008) A fuzzy mathematical method to evaluate the suitability of an evaporative pad cooling system for poultry houses in China. *Biosystems Engineering*. **101**(3): 370-375. <https://doi.org/10.1016/j.biosystemseng.2008.08.005>
- Watanabe, P., Azevedo, A., Augusto, M., Silva, N., Oliveira, N.M., Gomes, T.H., Andrade, S., Delfino, A., Barbosa Filho, J.A.D. (2019). Cooling ventilation at farrowing for sows from first to third parturition. *Comun. Sci.***9**: 556-564. <https://doi.org/10.14295/cs.v9i4.1098>.