17(3) 877-888, Autumn 2025

Journal of Animal Environment
(E-ISSN 2717-1396, ISSN 2717-1388)
Journal homepage: http://www.aejournal.ir

## Original Research Paper

# Microclimate Optimization in Semi-Intensive Livestock Housing Using Natural Ventilation and Structural Modifications

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**Key Words**

Natural ventilation, Microclimate optimization, Livestock housing, Heat stress mitigation, Structural modifications, Temperature–Humidity Index (THI), Animal welfare, Passive cooling, Semi-intensive production systems.

**Abstract**

The thermal stress and lack of ventilation of livestock housing, as well as the fluctuating humidity levels, are a common characteristic of livestock housing in tropical areas and in semi-arid regions, which influence animal welfare, health, and productivity adversely. The use of microclimate conditions towards sustainable livestock management is hence crucial in semi-intensive production systems of cattle and sheep that are commonly used in the sector. This paper explores how natural ventilation improvement and low-cost structural changes can help in the improvement of the indoor environment conditions in the current livestock housing units. The main solutions involved installation of constant ridge ventilation to facilitate escaping of air vertically, expansion of sidewall openings to encourage rising of air horizontally, using flexible shading screens to lower the radiant heating load on the building and use of reflective roofing materials to reduce the amount of heat taken in by the sun. The environmental parameters, such as temperatures, relative humidity, air speed and Temperature-Humidity Index (THI) were monitored and compared in modified and conventional housing units. At the same time, physiological measures of the animals such as rectal temperature, respiratory speed and the panting score were checked in order to determine thermal comfort. The altered architectures were with a consistent 35C lowering of the indoor temperatures, and a 1.21.8 m/s growth of the air circulation, and a significant decrease in the indicators of the heat-stress with the animals showing lower panting levels and stable body temperatures. These findings substantiate that structural interventions, such as highly specific low-cost ones, can greatly raise the effectiveness of natural ventilation, decrease heat stress, and play a role in the overall improvement of welfare and productivity of semi-intensive livestock systems. In general, the research represents the relevance and scalability of passive design interventions with regard to the promotion of sustainable and climate-resilient livestock housing.

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Received: 27 June 2025; Revised: 08 August 2025; Accepted: 08 September 2025; Published: 30 October 2025
**(DOI): 10.70102/AEJ.2025.17.3.71**

# Introduction

## Significance of Microclimate Control in Farmed Animal Housing

Control of microclimate plays a very important role in ensuring that livestock systems can operate optimally, with regard to physiological functions, welfare and productivity (Deepika et al., 2022). Temperature, relative humidity, and air movement are some of the environmental parameters that are directly related to feed intake, metabolic efficiency, immune status and production characteristics. Poor microclimate also causes a problem with thermoregulation that puts animals at risk of heat stress, respiratory distress, and a change of behaviour. Provision of a stable and comfortable microclimate is thus a major need of sustainable livestock management especially where climatic fluctuations are likely to occur.

## Problems in Semi-Intensive Housing Systems in Warm Climate

Semi- intensive livestock systems have become common in the production of cattle and sheep in tropical and semi-arid areas; although they have extensive difficulties in managing microclimate. Architectural factors affecting high temperatures and humidity in buildings are poor ventilation, low ceiling of roofs, the lack of shade, and the retention of heat. Such adverse conditions inhibit evaporative and convective heat losses in animals leading to lowered feed requirement, slowed growth, poorly constructed reproductive systems and deterioration of performance. Increasing global temperatures and common heat waves are also adding to the vulnerability of such systems.

## Engineering Advantage of Natural Ventilation and Structural Design Enhancements

Natural ventilation is a useful, inexpensive, and energy efficient solution to reducing heat stress among livestock in houses. Appropriate airflow channels assist in clearing up accumulated heat, movement of moisture, dilution of toxic gases and stabilisation of thermal conditions in the building. Passive cooling of the building is achieved through structural interventions like ridge ventilation, larger side openings, reflective roofing and shading mechanisms. The changes can strongly enhance the thermal environment when already in-built in current housing units without having to ventilate them mechanically or incurring a substantial level of cost of operation.

## Reason and Objectives of the Study

Although natural ventilation has undoubtedly been proven to be very beneficial, most of the traditional designs of livestock housing are outdated and ineffective in the current weather conditions. The study was thus done to understand how effective targeted structural changes are in enhancing the micro climatic conditions in semi-intensive cattle and sheep units. The goal was to determine an increase in temperature, humidity, air movement and THI caused by natural ventilations improvements and examine respective physiological reactions of the animals. There is an expectation that this research will provide the nucleus to implement sustainable and welfare-based housing services that can suit the small and medium-sized livestock farmers.

## Literature Review

### Microclimate Problems in Housing Livestock

The microclimate regulation is one of the key factors that determine the animal welfare and productivity, and in tropical and semi-arid areas, when animals are often subjected to the heat and humidity, this factor becomes highly significant. Through such conditions, animals that are exposed to environmental conditions beyond the thermoneutral zone are exposed to thermal stress subsequently leading to negative impacts on the metabolic balance, immune resilience, and efficiency in production. In past experiments have indicated that high level of Temperature Humidity Index (THI) causes severe degradation of performance in cattle and sheep, with significant changes upon index exceeding THI levels of 72 and 75, respectively (Cincović, 2010; Spiers et al., 2004). The stress of heat may enhance hyperthermia, a decrease in feed conversion performance, deceleration in growth and therefore decreases the yield of milk, and ultimately the decline in profitability of the farms. Additional physiological experiments confirm that heat-stressed cattle have higher rates of panting, high temperatures in the rectum, and a difference in metabolic responses as adaptive constraints to reduce the thermal load (Bernabucci et al., 2014; Spiers et al., 2004; Nathiya et al., 2023).

### Passive Cooling Strategy of Natural Ventilation

Most people are aware of natural ventilation as a method of overseeing the indoors temperatures in livestock houses as an energy-saving technique which is sustainable. Correct ventilation supports convective cooling, lessens water build-up, decreases concentrations of toxic emissions (NH 3, CO 2), and restricts the growth of pathogens. The active interventions that have been recognized in enhancing natural airflow and minimizing heat retention in the barns and agricultural shelters are known as ridge vents, expanded side vents, and elevation of roof structures (Ivanov & Novikov, 2020; Tikhomirov et al., 2020; Vtoryi et al., 2018). Experimental studies conducted in livestock housing indicate that efficient ventilation can also be used to stabilize the microclimate events within the buildings during times of peak summer stresses at very high rates (Vtoryi et al., 2018; Hristov et al., 2007). Moreover, deterministic and stochastic modelling investigations point to the fact that airflow in controlled settings like greenhouses can be used to predict the behaviour of microclimate in livestock habitats (Yang et al., 2019).

### Microclimate Optimization Structural Alterations

Cost-effective structural changes have been eminent in that they can be effectively used in the small and medium farms (Veerappan, 2024). Some of the important changes that have been demonstrated to reduce solar heat gain, as well as allow the movement of air include reflective roofing materials, adjustable shading structures, steeper roof slope, and wider overhangs (Ivanov & Novikov, 2020; Vozmilov et al., 2014). Reflective-coated roofs and especially the reflective-coated roofs have been efficient in minimising radiant heat loads, whereas the shading systems have played an important role in reducing direct thermal exposure in livestock shelters. Purification of air researches also focus on the need to keep the dynamics of airflow better to be able to reduce the air pollutants and lead to healthier living conditions (Vozmilov et al., 2014). All these innovations improve thermal capacity of natural ventilation systems to cool down the more passive cooling, which will eventually lead to an improvement in the level of animal comfort and less incidence of heat-stress.

### Technological Developments in Monitoring of Microclimates

The latest progress in the field of intelligent monitoring systems has made it possible to conduct the measurement of the level of microclimate in the environment of livestock housing in a more accurate way. Online platforms of microclimate control utilise real-time sensing technologies and maintain the temperature, humidity, and ventilation rates on a continuous basis enhancing environmental stability and energy efficiency (Ivanov & Novikov, 2020; Sereda & Kostarev, 2018). Lack of research It has been reported that automated ventilation control systems with heat recovery algorithms and airflow optimization algorithms have significant potential uses in agriculture, notably in livestock facilities that need a heavy emphasis on environmental control (Tikhomirov et al., 2020; Sereda & Kostarev, 2018). Even though these systems have typically been implemented in industrial or greenhouse situations, there are new opportunities to apply these technologies in semi-intensive livestock housing to promote the precision of astute monitoring and other adaptive management approaches (Sudhindra & Rajeswari, 2025).

## Materials and Methods

### Housing Design, Structural Interventions and Experimental Site

#### *Location and Climate of the Study*

The experiment had been done in a warm-humid agroclimatic area that was dominated by high ambient temperatures, relative humidity, and heat stress events that occur periodically typical in a tropical environment. Such climatic conditions render livestock especially sensitive to the effects of thermal discomfort, which is why the topic of microclimate optimization research should be justified. The location chosen was a semi-intensive system of livestock farming which keeps cattle and sheep under partially enclosed buildings. The baseline outdoor environmental data were also taken, to draw reference climatic conditions of the improvements of indoor microclimatics temperature conditions could be compared. This also made the difference in performance of the housing only dependent on the structural changes rather than the changes in weather.

### *Layout and Experimental Grouping Housing*

Two similar livestock housing buildings were chosen so that the required level of control of the experiment was provided and structural or design biases were avoided. The former was a Control unit, which kept the traditional semi-intensive house design with no ventilation system or thermal adaptation. The second unit turned out to be the Modified Structure, which involved specifics of microclimate improvement. The two units had the same size, roof height, and orientation, construction materials, and animal stocking density to preclude the fact that animals would undergo similar management conditions during the study. Bedding, daily care practises, and feed and water in both units were standardised, which eliminated the effects of structural interventions without mitigating the effect of the environment.

### *Outlay of Structural Changes That Have Been Implemented*

The Modified Unit had four major structural interventions, which aimed at enhancing the indoor movement of air and the minimization of heat. In the first place, the ridge ventilation was provided to allow the escape of hot air through stack effect by creating a continuous opening 30-45 cm on the roof ridge. Second, the sidewall openings were increased to 1.8 m as compared to 0.8 m to increase cross-ventilation and to allow the movement of cooler air at animal height. Third, removable shading sheets of HDPE or bamboo were attached to sun-facing sides to minimise the exposure to the radiant heat and allow changing the intensity of shading by the seasonal hum. Lastly, to reduce the surface heat in solar absorption and reduce surface temperature, reflective-coated galvanised roofing sheets were used. The choice of these modifications was determined by their cheapness, feasibility in practise, and compatibility to the existing livestock constructions.

### *Management Practise and Study Controls Standardisation*

All the management-related factors were standardised between housing units to ascertain the factor of experimental validity. The allocation of animals was done in terms of uniform physiological status, body weight, and health condition to reduce the biological variability Figure 1. The routines of feeding, access to water, change of bedding, cleaning and monitoring of health were being observed throughout the study. To eliminate confounding effects, both units did not have any mechanical ventilation or artificial cooling systems. The strict control design allowed the determination of any differences in microclimate conditions or physiological reactions of animals as being directly caused by the structural changes which were implemented, as opposed to the external management effects or operational discrepancies.

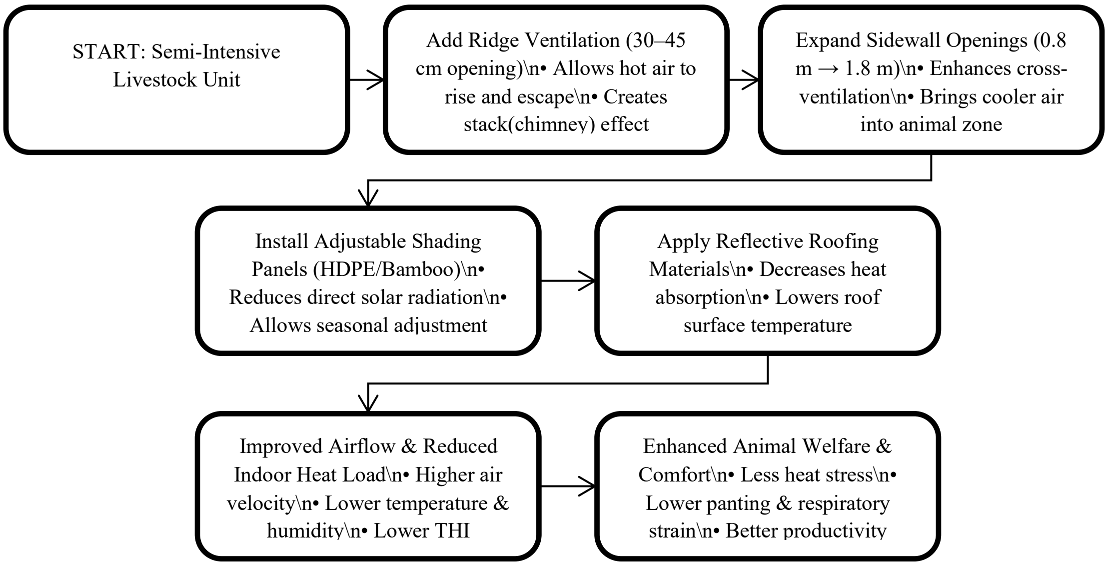


Figure 1: Flowchart of Structural Modifications and Resulting Microclimate Improvements in Semi-Intensive Livestock Housing

## Environmental Monitoring and Microclimate Measurement Protocols

### *Parameters and Instrumentation of Environment*

Extensive observation of the environmental conditions in the 45 days of study period was done to measure the microclimate of the control and modified livestock housing units. The selection of four important parameters such as air temperature, relative humidity, air velocity, and Temperature Humidity Index (THI) as critical parameters that indicated both the level of thermal comfort and the level of ventilation efficiency. Calibrated digital thermohygrometers with precision of 0.5 o C conducted air temperature and humidity, and hot-wire anemometers that can measure a reciprocity over the airflow as low as 0.1 m/s determined air velocity. Moreover, to record representative microclimate variations in the zone occupied by animals, electronic data loggers were placed at the less height (around 1.2 m above the ground level). These instruments combined to give precise and high-resolution data to determine the effectiveness of the structural interventions.

### *Sampling Schedule and Measurement Spatial Distribution*

Throughout the day, three fixed time points were used to collect the environmental data 08:00, 13:00 and 18:00 to obtain the morning, peak-heat and evening thermal patterns. Measurements were taken in three places at a distance in each unit of house to identify the variance in space with respect to temperature, humidity, and airflow. Such a triangulated approach to sampling guaranteed that microclimate measurements were able to capture general conditions in the indoors as opposed to localised deviations. Concurrent monitoring of the outdoor environmental conditions was used to provide reference values on outdoor conditions in order to compare indoor changes. Consistent measurements made in both units at consistent time and space ensured that the evaluation of diurnal variations and undertaking of energy saving by the two units could be assessed well.

### *Calculation and Classification of Thermal Stress Levels*

The level of heat stress experienced among the animals was determined as Temperature adjustment of Humidity Indices (THI) by a commonly used livestock thermal stress equation:

$$\mathrm{THI} = (1.8\mathrm{T} + 32) - (0.55 - 0.0055\mathrm{RH})(1.8\mathrm{T} - 26) \quad (1)$$

This index combines the cooperative impact of temperature and humidity on the thermal load on animals and it is possible to distinguish the conditions of microclimate as normal, alert, danger stressed and emergency stress. Using THI thresholds, the study could make objective comparisons of the level of thermal stress between the control and modified units and identify the comparative effect of ventilation improvements. THI was used to provide an important clue to accomplish environmental enhancement against possible welfare gains detected in cattle and sheep kept in the modified building.

## Comparative Steatosis Evaluation and Statistical Analysis in animals

### *Physiological Detection of Responses to Heat Stress*

In order to test the levels of thermal comfort in the animals, physiological indicators of heat stress were carefully observed in the control and altered housing units. The core body heat load measures by taking rectal temperatures of the animals using the digital veterinary thermometers, which were previously calibrated on a liquid thermo luminescence standard, and the respiratory rate of the animals was established by counting the number of flank movements in a 60-second time interval. Also, the intensity of panting was measured using a standardised 04 panting score scale usually used in the evaluation of heat stress used in livestock. To make a direct comparison between these physiological measurements and environmental parameter measurements and determine the relationships between microclimate conditions and animal responses, the environmental parameters readings were collected together with these measurements at the same time. The evaluation of acute and chronic heat stress in cattle and sheep could be conducted through recording various indicators.

### *Behavioural Observation Procedures*

The behavioural testing was done in order to complement the physiological test results and to give qualitative data on the comfort of the animals under various housing conditions. Observers who were trained recorded resting and posture patterns, feed consumption patterns, agitation, panting and spatial distribution patterns like clustering or dispersion in the pen (Janaki Sathya & Geetha, 2011). Such behavioral indicators are sensitive pointers of environmental stress and can indicate discomfort that might not be apparent when using physiological indicators. During the same time that the environment was measured, the same time was used in observations to have uniformity and relevance. A combination of behavioural data and physiological tests improved the general analysis of the impact of the housing microclimate on animal welfare.

### *Ordinary Statistics and Data Interpretation*

Data acquired were analysed with a strong statistical effect in which the strength and significance of any given relationship between environmental changes and the response of animals is obtained. ANOVA was used with one way to compare the environmental and physiological variables of the control and modified units considering the statistical significance of $p = 0.05$. Pearson correlation analysis was employed to measure relationships between physiologic attributes of THI like rectal temperature and respiratory rate that allowed determination of direct effects of microclimate on thermal stress Figure 2.

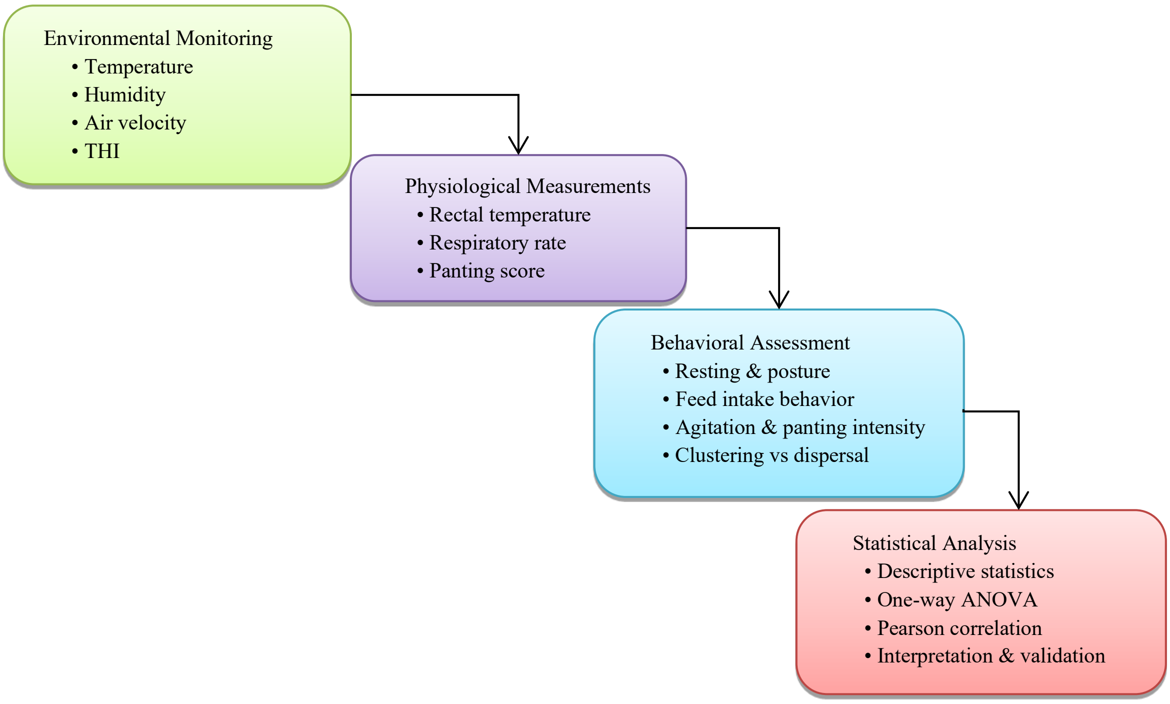


Figure 2: Workflow Diagram of Environmental Monitoring, Physiological Measurements, Behavioral Assessment, and Statistical Analysis in Livestock Heat-Stress Evaluation

Deviations and standard deviation as well as the range were determined as descriptive statistics that characterize the level of environment condition and animal welfare parameters during the study period. These methods of analysis provided predictable analysis of findings and proved efficiency of structural changes in improving microclimate and minimising heat stress.

## Results and Discussion

### Enhancement of the Microclimate Conditions

The essential changes which were made to the altered housing unit led to significant improvement in the conditions of the microclimate than those of the control structure. The temperature of the indoors was always lower by 3-5C and the adjusted unit showed an indoor temperature range of 2831 which was much lower in comparison to the 3336C in the control. Relative humidity had been reduced by 10-12 percent and Air velocity had improved drastically in the modified unit, 1.4-1.8m/s, compared to 0.2-0.4m/s in the control unit, by 350-600 per cent, respectively. In line with this, the values of THI in the modified unit were albeit within the safe thermal comfortable range (7286), but the control unit was often in the stress range (8286). Such results have made it very clear that natural ventilation improvements and passive structural adjustments have a role to play in reducing heat accumulations and enhancing indoor environmental stability.

## Physiological Reactions of Livestock

Improvement of the microclimate had a strong correlation with the physiological behaviour in cattle and sheep that directly supported thermal comfort. The respiratory rate of animals in the modified housing unit was significantly reduced, between 80-110 breaths a minute in the control group and 45 -65 breaths a minute in the modified, which represents a reduction in heat stress by about 40 percent. Panting scores also improved by 23-3 to 0-1 and this indicated that respiratory discomfort was alleviated significantly. Animals kept in the modified structure also had lower rectal temperatures, which were about 1.2 o C lower. Statistical correlations showed that there existed a positive moderate relationship between THI and respiratory rate (r = 0.82) and negative relationship between air speed and panting score (r = -0.72) showing that improved ventilation has a significant negative effect on physiological marks of heat stress.

## Behavioural and Welfare Observations

The behavioural observations also supported the beneficial effect of the structural changes on animal welfare. The livestock kept in the modified unit also had calmer behaviour and an increase in feeding behaviour and a higher number of postures which rested with thermal comfort. The decrease of ammonia smell indicated a better airflow and the lessening of harmful substances, which leads to the healthier environment. They also used shaded zones that were available through regulating panels, which made good relief especially during high sun radiation periods and therefore the animals were able to spread evenly in the area instead of congregating in areas that were cooler. These gains in behaviour emphasise the importance of microclimate control in enhancing physiological and natural behavioural manifestation in livestock.

## General Interpretation and Implication

The overall findings go a long way to support the fact that low-cost structural interventions could be transformational in terms of enhancing livestock housing in semi-intensive systems. The greater air movement created by the presence of the ridge ventilation and larger sidewall penetrations contributed greatly to the heat dissipation, which was convective and the solar heat gains and shading panels reduced radiant exposure Figure 3. All these interventions helped to reduce thermal load and stabilise the conditions of microclimate, which eventually decreased animal heat stress Table 1. Thermoregulation was also superior in animals kept at optimised structures as demonstrated by the reduction of panting, respiratory rate and rectal temperature resulting in increased metabolic efficiency and productivity potential. These results are consistent with the literature on the topic of passive cooling solutions and highlight the importance of the natural ventilation-based alterations in the context of sustainable management of livestock in hot climates.

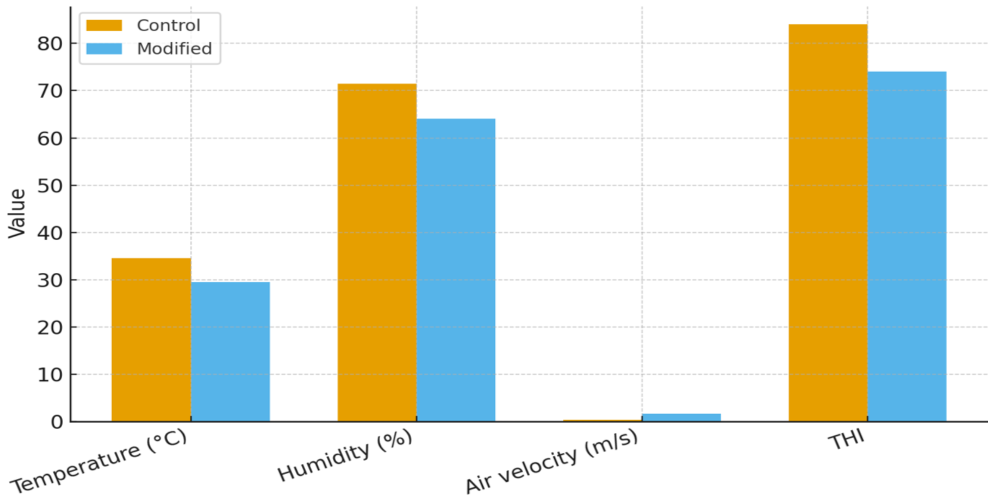


Figure 3: Comparison of Key Microclimate Parameters Between Control and Modified Livestock Housing Units

Table 1: Summary of Microclimate, Physiological, and Behavioral Improvements in Modified Livestock Housing

| Category | Parameter | Control Unit | Modified Unit | Improvement / Effect |
|---|---|---|---|---|
| **Microclimate Conditions** | Temperature (°C) | 33–36 | 28–31 | ↓ 3–5°C (lower heat load) |
| | Relative Humidity (%) | 68–75 | 60–68 | ↓ 10–12% |
| | Air Velocity (m/s) | 0.2–0.4 | 1.4–1.8 | ↑ 350–600% airflow |
| | THI | 82–86 | 72–76 | Maintained in safe zone |
| **Physiological Responses** | Respiratory Rate (breaths/min) | 80–110 | 45–65 | ↓ ~40% (reduced heat stress) |
| | Panting Score (0–4 scale) | 2–3 | 0–1 | Major reduction in heat stress signs |
| | Rectal Temperature (°C) | 39.5–40.2 | 38.3–38.8 | ↓ ~1.2°C |
| | THI vs Respiratory Rate | Strong correlation (r = 0.82) | Lower RR at lower THI | Ventilation directly improves comfort |
| | Air Speed vs Panting Score | Weak airflow causes higher score | Higher airflow → lower panting | Negative correlation (r = –0.72) |
| **Behavioral Responses** | Resting Behavior | Restless, frequent standing | More resting, calm posture | Improved comfort |
| | Feed Intake | Reduced during heat | Increased, stable | Better appetite |
| | Movement Behavior | Agitated, clustering | Calm, uniform distribution | Lower heat stress |
| | Odor (Ammonia) | Noticeable | Significantly reduced | Better ventilation |

| **Overall Interpretation** | Summary | Heat accumulation, poor ventilation | Cooler, better-ventilated environment | Enhances thermoregulation, welfare, productivity |
|---|---|---|---|---|

## Conclusion

This will show that there are inexpensive fixed structural improvements that can significantly improve microclimate of semi-intensive livestock housing systems; especially in warm, humid areas where heat stress can be a significant limit to the welfare and productivity of animals. Introductory measures to control indoor temperatures, which included ridge ventilation, enlarged sidewall openings, reflective roofing material, and adjustable shading panels, were successful in lowering physiological and behavioral evidence of heat stress in cattle and sheep, through reduction of indoor temperatures, air circulation, and sustainability of THI within safe, comfort proximal limits. These passive interventions are practical and can easily be scaled, provide superior respiratory and metabolic environments, and the thermal environment is stabilised, thus providing an energy efficient and constructive answer to the farmers who wished to enhance the performance of housing without the need to necessarily provide mechanical cooling. All in all, the results highlight the possibility of small structural improvement to facilitate sustainable livestock management, improve its welfare performance and create resilience to increased climatic stresses.

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